Greenhouse gas forecasting and target setting using an ex-post analysis

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Declaration

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

This dissertation includes one original papers published in peer-reviewed journals and two unpublished publications. The development and writing of the papers (published and unpublished) were the principal responsibility of myself.

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English - Abstract

Concerns about the impact of climate change are driving the need for stabilising the global temperature rise to below 2°C. In parallel to countries making commitments under the Paris Agreement, sector decarbonisation trajectories are being developed. Globally, collective action is required, and cities and companies are increasingly requested to voluntary set greenhouse gas (GHG) targets. Tracking progress is key to meeting the objectives of the Paris Agreement.

In order to track progress against a GHG target or commitment, a credible GHG inventory, as well as the associated emissions reduction from GHG mitigation actions, are required. An analytical technique was developed the present GHG inventory, corrected if needed, together with the GHG mitigation actions to construct a counterfactual baseline. This counterfactual baseline is compared to the GHG target in one infographic.

South Africa committed to a peak, plateau, and decline trajectory. However, the latest publicly available inventory is for 2010, but can be extrapolated based on trade statistics. The inventory is based on the default Tier 1 coal calorific values of the Intergovernmental Panel on Climate Change (IPCC) and could be over reported by 20%. A methodological approach is proposed, where the emissions from coal calorific value, together with trade statistics, are quantified and presented together with the GHG emission reduction estimates of implemented mitigation policies and measures.

Companies in the mining sector of South Africa voluntary signed a 15% GHG reduction over a ten-year period from 2005, linked to the South African Energy Efficiency Accord. GHG emissions increase as mining companies transport ore over increased distances in opencast operations, or extract ore from deeper levels in underground operations. The GHG inventories of a gold and an iron ore mining company, together with the implemented projects, are analysed to evaluate progress.

The decarbonisation trajectories of cities are linked to the implementation of national commitments and voluntary target setting commitments under the Global Covenant of Mayors. Within a developing country context, with rapid urbanisation and limited data, tracking the greenhouse gas inventory against the targets is challenging. This study looks at four cities in South Africa that made greenhouse gas reduction commitments and supplied inventory data into publicly available databases. The greenhouse gas data for each city is extrapolated based on official data from national census and socio-economic studies. The formal commitment to meeting the sustainable development goals was announced 2016, to providing basic drinking water, sanitation, electricity, as well as transport for citizens currently unemployed. This study provides insights into the trade-off between additional GHG emissions in

meeting the sustainable development goals in fast-growing cities of a developing country, and the decarbonisation commitment of these cities.

Tracking progress against absolute greenhouse gas reduction targets should take the uncertainties of the underlying data for GHG inventories, and mitigation outcomes, into account. Quantification of the emission reductions of implemented mitigation initiatives is critical in managing emissions against a GHG mitigation trajectory. The importance of this study is to enhance transparency in a data poor environment, while keeping the focus on mitigation action.

Afrikaans - Opsomming

Motivering om die wereldwye temperatuur onder 2ºC te hou word gerugsteun deur kommer oor die impak van klimaat verandering. In parallel met lande wat hulle verbind het om kweekhuisgasse te verminder onder die Parys Ooreenkoms neem sektore ook aksie. Globaal moet kweekhuisgasse verminder en maatskappye en stede word gevra om ook vrywillig kweekhuisgas doelwitte te stel om die wereldwye doelwit te behaal. Daarom is dit ook noodsaaklik om vordering te monitor teenoor die verskeie kweekhuisgas doelwitte.

‘n Analitiese metode is ontwikkel om kweekhuisgas inventarisse te korrigeer waar nodig, en saam met die verminderingsaksies te vertoon om so n denkbeeldige basislyn te bereken. Hierdie denkbeeldige basis lyn kan gebruik word om vordering teenoor die doelwit te bereken in een inligtingsdiagram. Hierdie metodiek is toegepas in drie verskillende situasies naamlik, nasional, stads en maatskappyvlak, as deel van drie gevallestudies. Die analitiese metode was toepasbaar op al drie hierdie gevallestudies.

In Suid Afrika is die laaste inventaris is goedgekeur in 2010. Hierdie inventaris is gebaseer op standaard vlak 1 IPCC steenkool kalorie waardes en is 20% meer as wanneer die werklike kalorie waardes gebruik word. n Metode word voorgestel waarmee die kweekhuisgas inventaris aangepas word met werklike steenkool kalorie waardes en n oorbrugging gedoen word met handelsstatistiek en kweekhuis gas vermindering projekte. Hiermee is dit makliker om die vordering te volg. Dit is veral sinvol vir lande waar die data onsekerheid is hoog of waar die nationale statistiek beperk is.

Maatskappye in die mynbou sektor van Suid Afrika het hulle ook vrywillig verbind aan ‘n 15% vermindering oor n tienjaarperiode vanaf 2005, die Energie Effektiwiteits Ooreenkoms. Kweekhuisgas emissies neem toe as mynbou maatskappye erts oor n langer afstand vervoer in oopgroef myne of erts dieper myn in ondergrondse myne. Die kweekhuis gas emissies van n goud en yster erts mynbou maatskappy, saam met die projekte wat geimplementeer is, word saam geevalueer om vordering teen die doelwitte te monitor.

Die kweekhuis gas trajek van stede hou verband met die implimentering van nasionale doelwitte asook ‘n vrywillige doelwit onder die wereldwye Burgemeester Ooreenkoms. In ‘n ontwikkelende land konteks met vinnige verstedeliking, maar ook beperkte data is opdatering van ‘n kweekhuis gas inventaris is baie moeilik. Hierdie studie het gekyk na vier stede in Suid Afrika wat kweekhuis gas doelwitte gestel het en inventaris data openbaar gemaak het. Die kweekhuisgas data, vir elke stad is geekstrapoleer op basis van national sensus en sosio-ekonomiese data. Die impak van ontwikkeling vir die volhoubaarheidsdoelwitte teenoor vermindering van die kweekhuisgasse is uitgelig, om insig te gee in probleme van vinnig groeiende stede in ontwikkelende lande.

Vordering teenoor doelwitte op hierdie manier neem die onsekerheid van die onderliggende data in die kweekhuisgas inventaris en verminderings inisiatiewe in ag. Kwantifisering van die kweekhuis gasse van verminderingsprojekte is noodsaaklik vir bestuur van n verminderings trajek en die behaling van doelwitte. Die waarde van hierdie metodiek is om helderheid te verkry in n data arm omgewing terwyl die fokus bly op verminderings aksie.

Publications based on this research

As a technical working group member of GHG Protocol Mitigation goal standard, convened by the World Resources Institute (WRI), the early work that became the basis of this paper is published as pilot tests in the following standards:

- GHG Protocol Mitigation goal standard as *Calculating additional emission reductions needed to achieve South Africa's mining sector goal* (GHG Protocol, 2014, page 105)
- GHG Protocol Policies and actions as *comparison of ex- post and ex- ante results for energy efficiency policies in the south African mining sector* (GHG Protocol, 2014b, page 131)

Three articles and a separate abstract were also written based on this research and submitted for publication.

- The first article was published in February 2018 by the Journal for Energy in Southern African.

  Title: Tracking decarbonisation in the mining sectors (Immink, Louw, & Brent, 2018)

- The second article was submitted to the Journal for Environment, Development and Sustainability in May 2018, revisions were requested, and submitted in December 2018.

  Title: Country Specific Low Carbon Commitments Versus Equitable and Practical Company Specific Decarbonisation Targets

- A third article was submitted to Climate Policy in June 2018, awaiting feedback from the reviewers.

  Title: Tracking the decarbonisation of South Africa while dealing with national GHG inventory variations and data gaps: A new methodological approach

Under a call for abstracts, for a special issue, of the Urban Climate Journal on “Urban data and climate information services” an abstract was submitted in July 2018, awaiting selection decision from the editors.

Title: The decarbonisation trajectory of four metropolitan cities in South Africa, a new methodological approach.

Principle theme: Use of climate change information services in / by cities with the research question of how to deal with the challenges of matching information needed with information available.

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- Robbie, who has a light in his thinking and wants to make the world a better place.
- Alan, the dude who was willing to take a chance on me.

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List of acronyms and abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
AR5	IPCC fiftth assessment report
ARC	Agricultural Research Council
BRT	Bus Rapid Transit
BUR	Biennial Update Report
CAIT	Climate Analysis Indicator Tool
CNG	Compressed Natural Gas
CDP	Carbon Disclosure Project
CDM	Clean Development Mechanism
CH_4	Methane
CO_2 eq	Carbon Dioxide Equivalent
GPC	Global Protocol for Communities
DEA	Department of Environmental Affairs
DME	Department of Minerals and Energy
DSM	Demand Side Management
EE	Energy Efficiency
EIA	U.S Energy Information Administration
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GRI	Global Reporting Initiative
Gt	Giga Tonne

IEA	International Energy Agency
IGCCC	Intergovernmental Committee on Climate Change
INDC	Intended Nationally Determined Contributions
IPAP	Industrial policy action plan
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producers
Mt	Mega tonne
MRF	Materials recovery facility, materials reclamation facility, materials recycling facility or multi re-use facility
NCCRWP	National Climate Change Response White Paper
NDP	National Development Plan
NBI	South African National Business Initiative
RE	Renewable energy
SDG	Sustainable Development Goal
TWh	Terra Watt hours
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WBCSD	World Business Council for Sustainable Development
WMO	World Meteorological Organisation
WRI	World Resources Institute

1. Introduction

1.1. Background to the research

The industrial revolution in the nineteenth century was made possible by the availability of fossil fuels, such as oil, gas and coal. Today fossil fuels still support industrial activities worldwide, especially in industries that are energy intensive, such as mining and mineral processing. In countries where coal is available as an abundant natural resource, it provides a very affordable fuel source for the electricity grid. The carbon contained in fossil fuels oxidises during combustion and transforms into Greenhouse Gases (GHG), such as CO_2, while releasing energy. The increase in GHG in the atmosphere combined with increased deforestation is changing the climate (IPCC, 2014).

There is concern from scientists, economists and politicians about both the impacts of climate change and the cost of not taking action (Stern, 2014). These concerns are driving a deeper look at options for GHG reduction as well as the setting of GHG budgets, goals and targets by nations around the world. Although the initial action was taken by the United Nations (UN) through international agreements and protocols, increasingly civil society and private sector are becoming involved in climate change actions, Despite this GHG emissions into the atmosphere keeps increasing (UNFCC, n.d.).

1.1.1. GHG emissions

The first agreement between nations to mandate GHG reductions was the Kyoto Protocol. This Protocol transpired during the 1992 United Nations Framework Convention on Climate Change[1] (UNFCCC, 1995), also known as the Earth Summit. The framework was signed by nearly all the nations, and the objective is to stabilize GHG concentrations "at a level that would prevent dangerous anthropogenic interference with the climate system"(UNFCCC, 1995, page 5) . The Protocol, with binding targets for some countries, was finalized in Kyoto, Japan, in 1997, after years of negotiations (UNFCC, 1998). It subsequently came into effect in 2005 for a ten-year period, using 1990 as the base year. Progress was only tracked on respective absolute GHG emissions inventories of the countries or regions that had binding targets.

[1] www.unfccc.int

The Intergovernmental Panel on Climate Change[2] (IPCC) is an international body that assesses the science of climate change. The IPCC was jointly set up by the World Meteorological Organization[3] (WMO) and United Nations Environment Programme[4] (UNEP) in 1988. The IPCC provides regular assessments of the science around climate change and its impacts, as well as future risks and options for mitigation and adaptation. The IPCC assessments, therefore, provide a scientific basis for governments to develop climate-related policies, and they support negotiations at the UN Climate Conference. The assessments are policy-relevant but not policy-prescriptive. They may present projections of future climate change, based on different scenarios and the risks that climate change poses, or discuss the implications of response options, but they do not tell policymakers what actions to take. The IPCC assessments are written by a large number of leading scientists who volunteer their time and expertise as coordinating lead authors and lead authors of the reports. They enlist many other experts as Contributing Authors to provide complementary expertise in specific areas. The decision to prepare a Fifth Assessment Report (AR5) was taken by the members of the IPCC in April 2008. This assessment was focused on three working groups:

- Working group 1: The physical climate science
- Working group 2: Impacts, adaptation and vulnerability
- Working group 3: Mitigation of climate change

The release of AR5 by the Intergovernmental Panel on Climate Change (IPCC, 2014), showed that global climate change-related action is not happening fast enough. Total anthropogenic GHG emissions have continued to increase since 1970 despite a growing number of climate change mitigation policies. Between 2000 and 2010, annual global emissions grew by, on average, 1.0 gigatonne carbon dioxide equivalent (Gt CO_2 eq) a 2.2% increase year on year. This is significantly higher than the 0.4 Gt CO_2 eq increase in the period between 1970 and 2000, which was only a 1.3% total increase year on year (IPCC fifth assessment reports, Working group 1). Furthermore, it is suggested that faster action is required to prevent the onset of catastrophic climate change impacts.

AR5 concludes that it is important to remain focused on GHG mitigation policies and actions to ensure that GHG emissions are constrained (IPCC fifth assessment reports, Working group 2). At the time that the Kyoto Protocol was negotiated it was envisaged that the combined mitigation policies and associated

[2] www.ipcc.ch

[3] www.wmo.int

[4] www.unep.org

climate actions by participating countries would result in either a slower increase, or a decrease in GHG emissions that would limit the average temperature increase to 2° C. In preparation for a new global agreement countries had to outline and commit to post-2020 climate actions they intended to take, under a new international agreement, the Paris Agreement (UNFCCC, 2015).

Tracking national progress against international commitments has, therefore, gained importance since the parties under the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement in December 2015. The Paris Agreement is a framework to guide international efforts towards reducing GHG emissions and the associated climate change challenges (UNFCCC, 2015). After signing and ratifying the Paris Agreement, the respective countries started to implement the commitments, as proposed in their respective National Determined Contributions (NDC). The aggregated commitments should reduce GHG emissions to the overall goal of limiting the average global temperature increase to well below 2^0C. To date, the proposed aggregated commitments are not sufficient and more ambitious reduction targets are required to meet the objective of the Paris Agreement (Rogelj, Elzen, et al., 2016).

While national contributions are negotiated in the international domain, private companies (irrespective of the size), and concerned city management, are already calculating their GHG emissions inventories and are voluntarily reducing GHG emissions. Increasingly, the vital role of cities and businesses -both in implementing reduction initiatives (mitigation) and coping with climate change (adaptation)- are being recognised in international negotiations (such as Article 6 of the Paris Agreement), and in regional and national climate change strategies.

1.1.2. South Africa's climate change response

The South African climate change response is guided by the principles set out in the Constitution, the Bill of Rights, the National Environmental Management Act, and the Millennium Declaration. The overall vision is contained in the Climate Change Response White Paper (NCCRWP), with two main objectives:

- "To effectively manage inevitable climate change impacts through interventions that build and sustain South Africa's social, economic and environmental resilience and emergency response capacity.
- To make a fair contribution to the global effort to stabilise GHG concentrations in the atmosphere at a level that avoids dangerous anthropogenic interference with the climate system within a timeframe that enables economic, social and environmental development to proceed in a sustainable manner." (Department of Environmental Affairs, 2011)

South Africa ratified the Paris Agreement in November 2016 and committed to reducing GHG emissions on a peak, plateau and decline trajectory (Department of Environmental Affairs Republic of South Africa, 2015). This trajectory includes a target of reducing its GHG emissions to between 398 and 614 $MtCO_2$ eq (incl. land use, land use change and forestry (LULUCF) emissions), over the period 2025–2030. This target, however, is equivalent to a 20-82% increase on 1990 levels excl. LULUCF, as it is a target against a business-as-usual scenario (Department of Environmental Affairs Republic of South Africa, 2013) . The latest GHG inventory of South Africa covering the period 2000 up to 2012 was published in 2017.

Despite having ratified the Paris Agreement, there is currently no regulatory requirement to reduce emissions or to set GHG reduction targets in South Africa. An increasing number of companies have, however, voluntarily implemented emissions reduction initiatives, disclosed GHG inventories, set GHG mitigation targets, and publicly disclosed GHG targets. Although there is no official data on sectoral-specific performances the overall GHG intensity of the South African economy reduced in the period between 2000 and 2010 (Department of Environmental Affairs, 2013). Due to the fossil fuel intensive nature of electricity generation in South Africa, the energy sector remains the main contributor to GHG emissions (>80%). To mitigate GHG emissions while adopting a low carbon growth path will, therefore, require both an ambitious renewable energy target and an energy efficiency programme (Tyler, 2010). Significant improvements in energy efficiency could provide greater opportunity for economic growth while also providing broader access to energy and related services. While South African has constraint generating capacity and limited generating capacity being added in the foreseeable future, energy efficiency is the only intervention that could still support economic growth, with the current electricity availble. Also, improvements in energy efficiency show the greatest potential of any single strategy to abate global GHG emissions in the energy sector. The International Energy Agency estimated a global abatement potential of as much as 44% in 2035 that can be derived from energy efficiency measures (IEA, 2012).

Setting targets and monitoring the progress against these targets will require new analytical techniques. Improved accuracy in forecasting and identifying the key indicators to measure and report are of increasing importance in the development of an integrated emissions target framework. An analytical approach to target setting and GHG reporting is, therefore, required, not only by South Africa, but by all stakeholders with commitments to reduce emissions.

1.1.3. Reporting of policies and actions

There are two ways of analysing the impact of actions or policies: either modelling what it could be in the future (ex-ante), or evaluating the effects that have occurred as a result of a policy or action (ex-post). The ex-post analysis is an analytical technique that has successfully been used since the 1990s to evaluate and monitor, mainly, climate change adaptation. Jaffe et al. (2005) and Kolstad (1996) modelled adaptation with respect to the efficiencies of policies, with an ex-post analysis. Ex-post analyses of real-life cases of extreme events was also used in adaptation policy development, together with an ex-ante evaluation of expected climate change preparedeness, as a useful diagnostic tool (Runhaar et al., 2016).

As this is seen as an effective analysis of adaptation policies it could work for evaluating other climate change related policies. This is also supported by the recent publication of an ex-post analysis of the compliance of the Parties to the Kyoto Protocol based on final submissions of national GHG inventories and exchanges in carbon units (Shishlov, Morel, & Bellassen, 2016). In comparing effort and ambition on mitigation effort for the post-2020 climate policy contributions by China, the European Union, Russia, and the United States, a framework of combining ex-ante and ex-post reviews (Aldy, Pizer, & Akimoto, 2017). This is however a far future scenario comparing emissions, price and cost metrics for mitigation (Aldy et al., 2017). The focus of the verification for tradeable emission reduction units of the UNFCCC has been ex-post against compliance of actions with the predefined standards, methodologies, and commitments (Dagnet, Fei, Elliott, & Qiu, 2015). However this has not yet been used verify the progress of countries against their individual commitments.

Although the World Resources Institute has developed listed five benefits of an ex-post assessment it was aimed at the evaluation of policies and actions and supporting the causal chain analyis (World Resources Institute, 2013). These five benefits were to:

• Evaluate policy effectiveness and understand whether implemented policies and actions are delivering intended results

• Learn from experience to identify and share best practices, improve policy design, and decide whether to continue current activities or implement additional policies

• Evaluate the contribution of policies and actions toward GHG reduction goals

• Ensure policies and actions are cost-effective and that limited resources are invested efficiently

• Report on the GHG effects of policies and actions over time

• Meet funder requirements to estimate GHG reductions from mitigation action

The proposed diagrammatical interpretation is presented in figure 1-1

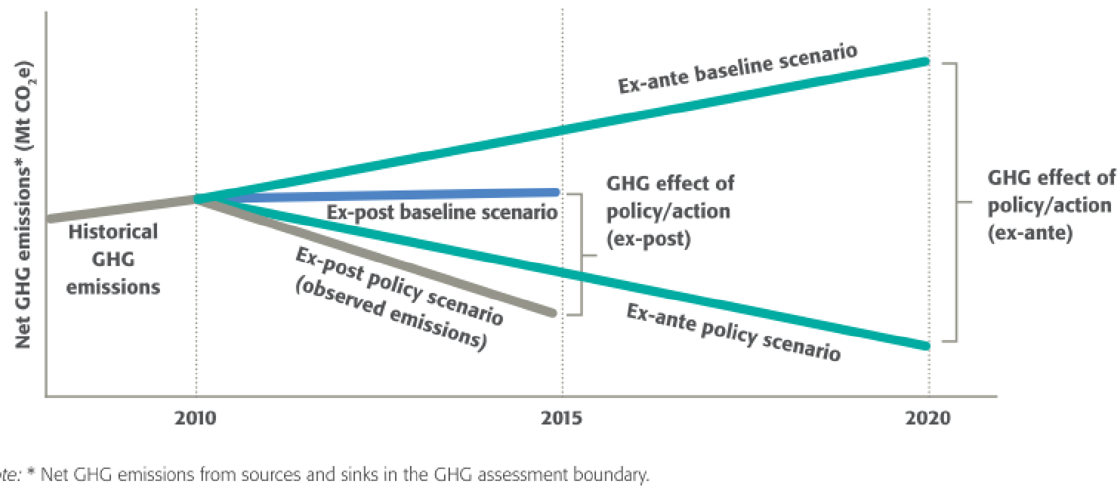

Figure 1-1: Proposed ex-post and ex-ante assessments to evaluate the GHG effect of policies or actions

Source: WBCSD/World Resources Institute, Policy and Action Standard, page 23

Over the past five years there has been a 45% increase of the volume of national climate policies worldwide (Dubash & Hagemann, 2013). The increase is supported by a survey of all the 193 United Nations countries for the period between 2007 and 2012 that indicated a global increase of climate legislation and strategies of, at least 23% by countries, at least 36% by population, or 45% by emissions

(Dubash & Hagemann, 2013). These national climate policies represent strategies, roadmaps and the subsequent impact of the mitigation actions would require practical analytical techniques for measurement and evaluation.

Evaluating the timing of implementing adaptation actions either after (ex-post) an event, or upfront (ex-ante) implementation, has been done by scholars such as Mendelsohn (2000). These studies showed that care should be taken in climate change performance measurements, control and accounting, to ensure that the chosen indicator is relevant in the climate change mitigation debate. Cooper and Pearce (2011) undertook a similar evaluation on the relevance of indicators in evaluating climate change response on a local government level, and found the indicators in terms of appropriateness, accuracy and timeliness problematic, and sometimes outside the control of the local government. The interaction of policies and actions can indeed be complex and should be seen in the context of the political sphere of each region (Hoppe, Wesselink, & Cairns, 2013).

As GHG reporting methodologies have improved and activity data has become available, GHG reporting has improved. However, GHG reporting may improve, and mitigation may be increased, while the overall GHG reduction is only negligible. Specifically improvements in energy efficiency can be outstripped by business growth (Sullivan & Gouldson, 2013). This does indicate a need to expand the GHG reporting to include the mitigation actions, before setting or renewing targets.

1.2 Justification for the research

In the transition towards a low carbon and climate resilient society, it is increasingly important to monitor progress. Therefore, GHG inventory calculations, forecasts, public GHG reporting and target setting, previously very different disciplines, have to support the cities, companies and countries, in making this transition. Fast-growing cities, emission-intensive companies, such as mining, and countries linked to an emission-intensive energy grid, such as South Africa, need practical tools to support evaluation and need to avoid misrepresentation or misinterpretation. In addition, particularly in a developing country context, the data gaps in inventories must be overcome to keep focus on implementing climate action in addition to the development of new roadmaps, policies and strategies. This research on the use of ex-post analysis may be able to support the development or applications of GHG accounting standards and policies.

The GHG Protocol Policy and Action Standard does not cover the light green aspects highlighted in figure 1.2.

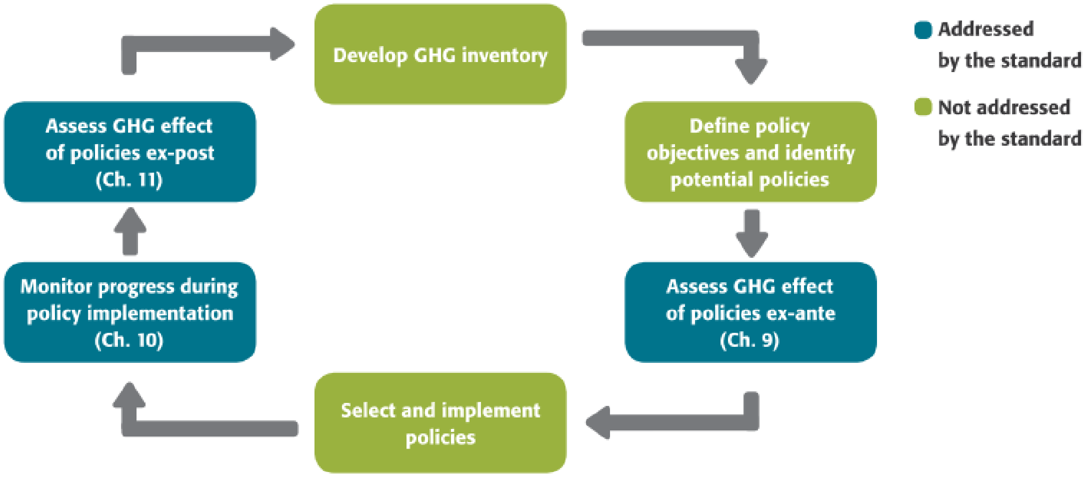

Figure 1-2 The coverage of aspects in the GHG Protocol Policy and Action Standard

Source: GHG Protocol Policy and Action Standard

This paper fills part of the gap in two of the aspect in figure 1.2, the development of the inventory and in the implementation of mitigation policies.

The link between the different aspects of greenhouse gas management is presented in figure 1.3. This paper aims to contribute to the four light green highlighted areas in the diagram below.

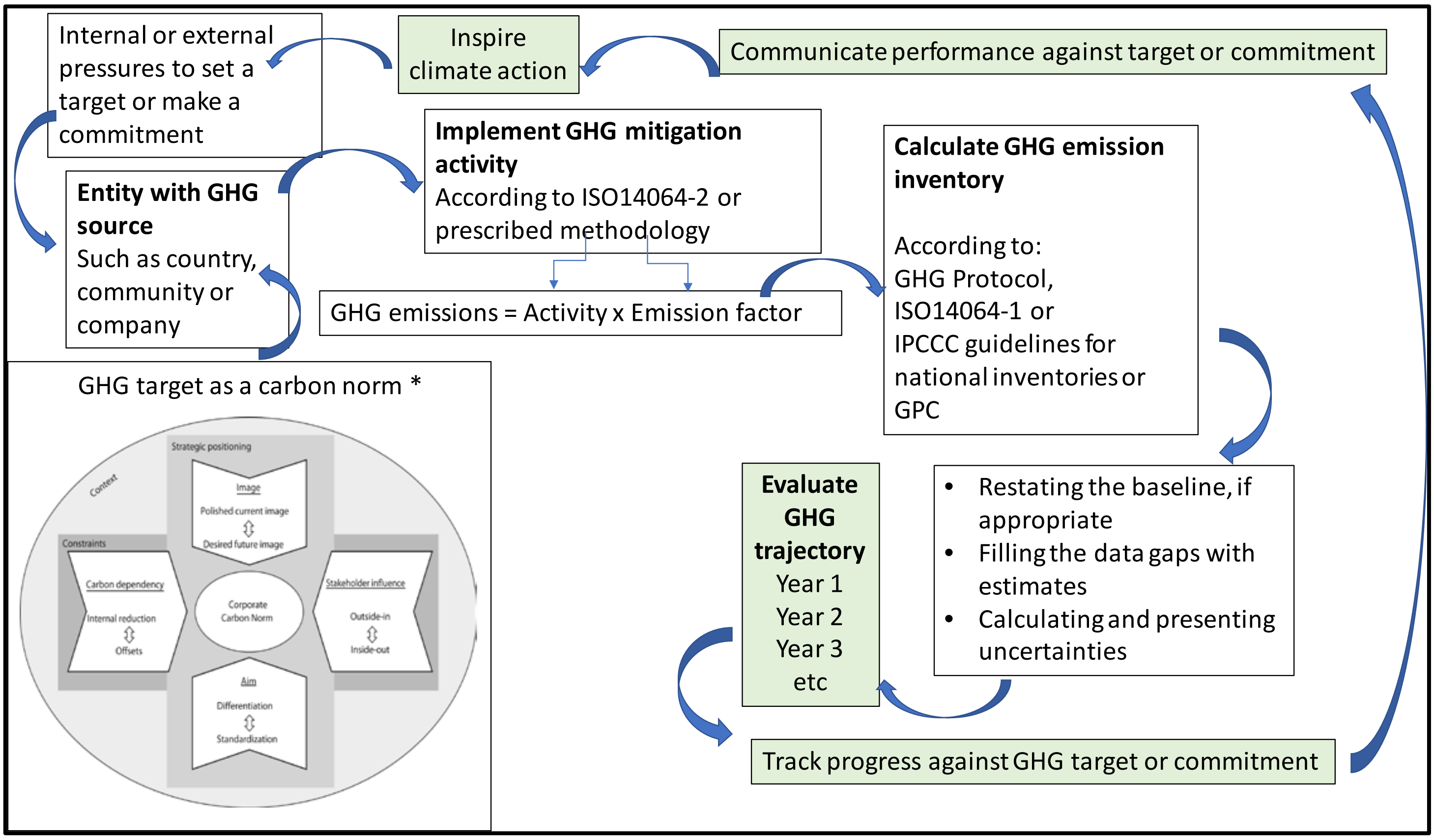

Figure 1-3 Interaction of GHG reporting and tracking performance against GHG targets, where the GHG target is a carbon norm

Source: interaction schematic developed by author. The carbon norm interaction is from the article, Emergence of corporate norms: strategic direction and managerial implications ((Pinkse & Busch, 2013)

1.3 Research problem statement and research questions

This paper aims to evaluate historical GHG emissions data against forecasts, from South African entities, in order to facilitate improved GHG target setting and monitoring. The problem statement, and related questions, are summarised in Figure 1.1.

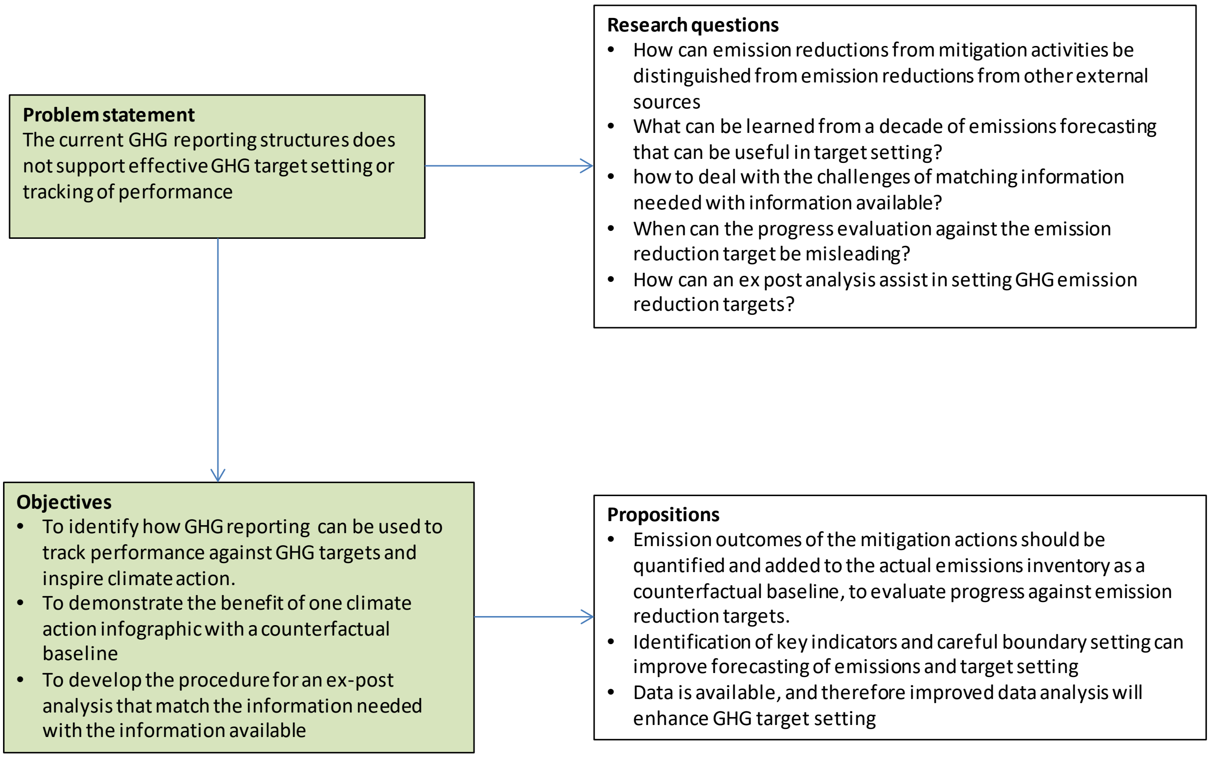

Figure 1-5 The research problem statement and objectives

The main research objective is to identify how the ex-post analytical technique could assist in tracjking progress against targets and improved GHG target setting. By answering the research questions, the ex-post analytical technique is evaluated, and the appropriate context and limitations of this analytical technique are identified under three different contexts, namely: national, company-specific, and metropolitan cities. Other research objectives are to develop a climate action infograph and to develop a procedure for the ex-post analysis to overcome data gaps in a data poor environment to support the transition to a low carbon economy.

This thesis is subsequently consolidated into a seven-chapter structure:

Chapter 1 contains the introduction and high-level overview of the approach to this research.

Chapter 2 contains the conceptual literature study that provides the body of knowledge from which the research problem and research questions emerged.

Chapter 3 describes the methods used in this research for data collection.

Chapter 4 presents the application of the analytical technique and the results of the data analysis on the South African national GHG inventory.

Chapter 5 presents the application of the analytical technique and the results of the data analysis in an underground gold mining company and an opencast iron ore mining company in South African.

Chapter 6 presents the application of the analytical technique and the results of the data analysis on four South African cities (Johannesburg, Tshwane (Pretoria), eThekwini (Durban) and Cape Town).

Chapter 7 concludes with the implication of this research and the research problems based on the results of chapters four to six.

Chapter 8 contains all the references used in this paper.

Chapter 9 contains the data and extrapolations done to develop the climate action infographs

1.4 Research strategy

The overarching problem statement is that the current GHG reporting structures do not support effective GHG target setting or tracking of performance. There is no integration of the various mitigation actions with the GHG inventories. Therefore, in broad terms, the research strategy consist of five distinct tasks as detailed below.

The first task is a *conceptual literature review*. This literature review focuses on the different key concepts related to GHG reporting and the extent to which each concept has been expanded to allow for interaction between the various concepts. The concepts and the initial literature review is described in more detail below.

The second task is to *identify the gaps* in the interaction between these complimentary concepts. Especially where the concepts are not expanded, the interaction or use in conjunction with other concepts is significantly reduced. Energy-related mitigation actions that do not extent to the associated GHG reduction is a very clear example of where the energy saving in units of energy can be translated to GHG savings but, building energy efficiency improvement or light bulb switch initiatives in themselves cannot be translated to a GHG reduction. At the country level the boundaries are prescribed and agreed to internationally. However, on a city and company level the boundaries are constantly changing and without clear reporting of boundary selection in the baseline the GHG trajectory can become vague. Public reporting of GHG inventories, without a reference to the emission factors used, are difficult to extrapolate or update. It is also difficult to quantify the impact of efficiency of policies or strategies, as the reporting could have been based on outdated or inappropriate emissions.

The third task is to *develop the ex-post analytical technique* based on the interaction of the various concepts. Four concepts, the forecast baseline, counterfactual baseline, inventory and mitigation actions provide the required input for the integrated ex-post analytical infograph.

The fourth task is to *evaluate the use of the ex-post analytical technique* in different contexts. Three different contextual evaluations form part of this research: mitigation on a national level, mitigation on a company level, and mitigation on a community (or city) level.

- The national level context is around fossil fuel consumption and the associated projections of emissions in South Africa,
- The company-level context considers an energy-intensive sector such as the mining sector to allow for visibility of the different concepts with the ex-post analytical technique,and
- The community-based context is based on four South African cities.

It is expected that the extent to which the different concepts have been developed will be of varying levels of maturity. For example, the GHG inventory might have been verified, but is presented without a clear description of the boundaries and underlying uncertainties, and the various mitigation actions are not quantified, or the assumptions behind the GHG goal might not be articulated. This supports the evaluation of the ex-post analytical technique as being appropriate and functioning within each context.

Finally, the fifth task of this research is to *conclude on the appropriateness of the ex-post analytical technique* for the different contexts researched. Within each contextual application, a step-by-step framework is developed for the ex-post analytical technique in forecasting and setting targets.

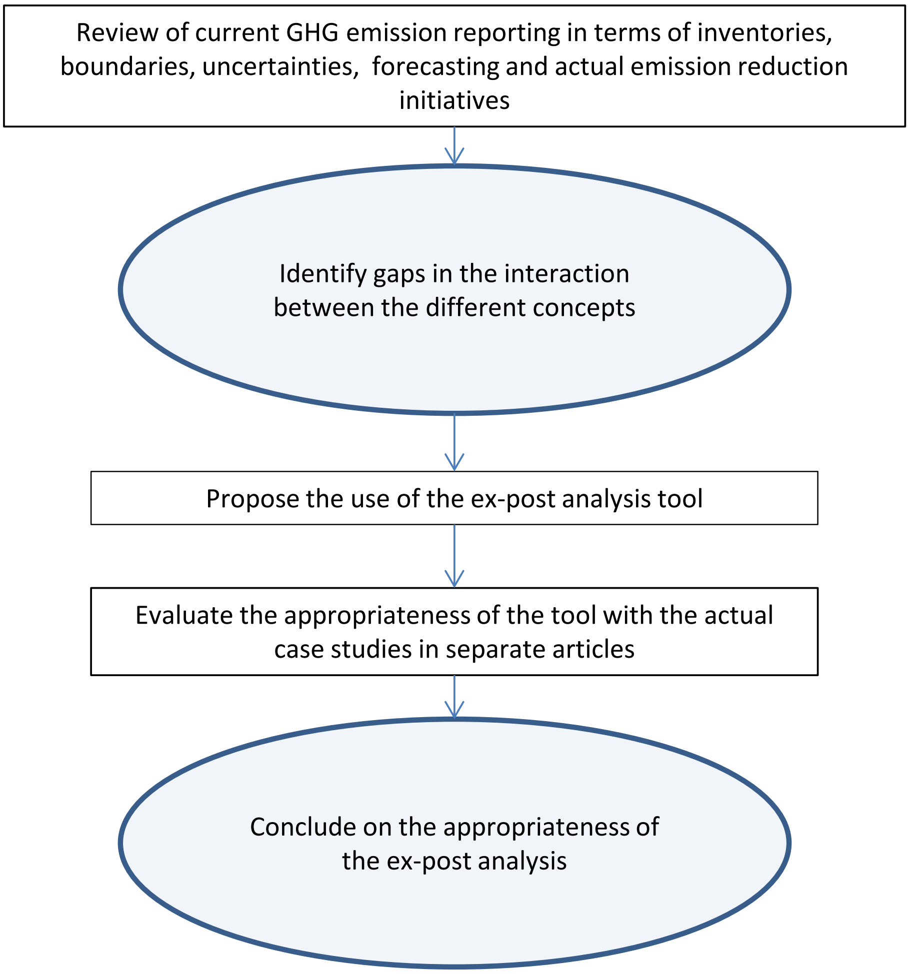

Figure 1-6 The strategy of the research study

1.5 Ethical considerations

As this study considers GHG commitments or GHG targets, which could be in the form of public commitments, there is a risk that the evaluation might show either a lack of progress or targets not being met. This could be seen as a lack of political or managerial will, or a failure to take the transition to the low-carbon economy seriously. On the other hand, meeting targets might lead to a conclusion that the targets were not ambitious enough to start with, which could also be a failure to take the transition to the low carbon economy seriously. Therefore, careful wording is required in presenting the research and analysis. The probability of this research causing harm is minimal.

Where a specific company's or entity's data is analysed, permission was requested to do so. The research does not involve direct interaction with human participants, nor is it linked to personal identifiers and it does not require information about an institution that is not in the public domain.

There is no need for confidentiality of the research, as the data is in the public domain and the various case studies applied to the model were, or will be, published in a series of journal articles.

This research received ethical clearance from the Research Ethics Committee Human Research (Humanities) on 14 June 2016.

1.6 Limitations and key assumptions

The limited volume of forecasting GHG data and targets, in the public domain, necessitated a careful selection of companies, sectors, and cities.

This study commenced before the COP21 in Paris, where key decisions on GHG accounting and target setting were agreed on. The role of non-state actors is acknowledged, but specific agreements on how to account for mitigation actions had not yet been reached by the commencement of this study. The direction of the negotiations and the individual country positions are, therefore, assumed to be outside the scope of this research.

In South Africa the proposed policy and regulatory environment is uncertain and is directly linked to a political direction within a shrinking economy. The approach of this analytical technique is assumed to be independent of political positions.

The study develops an analytical technique that is tested in three different contexts: national, energy-intensive companies, and cities in South Africa. The results are, therefore, limited to application within these specific case studies, although they could potentially have wider applications.

2. Literature analysis

2.1. Introduction

There is already more than a decade of GHG information, mitigations plans and commitments towards targets. The objective of this literature analysis is:

- to track GHG inventory reporting, over time, against the historic forecasts, with data available in the public domain,
- to investigate how reduction technologies and initiatives are reported as mitigation actions, and
- to evaluate how targets are reported as well as progress aginst these targets.

There are three main focus areas:

- The South African national GHG inventory and voluntary GHG reductions already implemented or presented.
- GHG targets and forecasting of mining companies under the 2005 energy efficiency accord of the Department of Minerals and Energy
- GHG inventories and mitigation actions of South African cities.

Climate Change research is both an interdisciplinary and intradisciplinary area, and as such, the theory and literature analysis supports a body of knowledge that could underpin this research, and also clearly articulate the gap in the peer-reviewed literature.

2.1.1. Approach to the theory and literature review

A conceptual literature review approach is undertaken that aims to synthesise the areas of conceptual knowledge that can contribute to a better understanding of ideas around GHG targets (Roberts, Petticrew, Roen, & Duffy, 2006). The objective was to review and synthesise the main ideas, models and debates within the GHG reporting, GHG mitigation and climate change target setting area. Therefore, the literature research covered the studies that looked at the approach and limitation to GHG reporting to date, the framework for reporting GHG saving activities, such as energy efficiency, boundary setting of GHG inventories and the methodologies, processes or analytical techniques commonly used in evaluating progress towards a set goal or target. These studies were grouped to identify their common core themes, elements and methods (Cronin, Ryan, & Coughlan, 2008). The literature review used these to identify systematic theoretical and methodological biases in the field of GHG reporting on targets, and suggest a fundamental reorientation of presenting progress against GHG targets (Alvesson & Orgen, 2011).

2.1.2. Framework for the conceptual literature review

This section draws on already existing literature in the field with a focus on reputable research organisation such as Harvard environmental economics programme, Cambridge Institute for Sustainable Leadership, and the Energy Research Centre.

The conceptual literature review evaluated the way GHG information is reported and how far this information is calculated or communicated as climate action or progress against a greenhouse gas target.

The six concepts in carbon management cycle of plan, do, check and act that are included in this review are:

- GHG reporting in terms of GHG policies, actions and inventories of companies, cities and countries;
- GHG mitigation actions, such as energy efficiency initiatives – with a specific focus on the actions within the energy-intensive mining sector;
- Uncertainties in reporting mitigation actions;
- GHG targets, commitments or GHG goals;
- GHG forecasting or GHG projections; and
- Monitoring or tracking of GHG performance against set targets or goals.

This paper builds on the existing GHG accounting frameworks, guides and standards that support entity specific inventories, in order to use the information in the analysis and the communication of the emission trajectories. These key documents are:

- 2006 IPCC Guidelines for National Greenhouse Gas Inventories
- ISO 14064-1:2018 Greenhouse gases – part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals
- ISO 14064-2:2006 Greenhouse gases -- Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements

- GHG Protocol Global Protocol for Community-Scale Greenhouse Gas Emission Inventories, An Accounting and Reporting Standard for Cities
- GHG Protocol Corporate Accounting and Reporting Standard
- GHG Protocol Policies and Action Standard, an accounting and reporting framework for estimating the greenhouse gas effects of policies and actions

2.2. GHG emissions inventory reporting and forecasting by countries

Countries or regions publish GHG inventories, inventory trends or forecasts. Countries that have ratified the Kyoto Protocol are required to make a national inventory of anthropogenic GHG emissions (by sources) and removals (by sinks) (UNFCC, 1998). The Biennial Update Reports (Department of Environmental Affairs Republic of South Africa, 2017) also contain forecasted GHG trajectories.

Over the past years, funding and assistance have been available by the Global Environment Fund (GEF) to support countries in submitting inventories for a calendar year that does not precede the submission date by more than four years. However, out of the 195 countries that provided GHG emissions for Article 21 of the Paris agreement in 2015, the average age of publicly presented inventories is ten years before submission (UNFCCC, 2015). When the UNFCCC collated this GHG inventory data, to determine a global budget, the top three GHG emitting countries contribute to 29% of global emissions. The inventory dates of the top three emitting nations were recent - within two years of publication. With the inclusion of India (inventory date of 2000) and China (inventory date of 2005), a total of 59% of emission data is covered. Although the individual decarbonisation trajectories for the remaining 190 countries are directly linked to their respective, outdated inventories, the impact on the global decarbonisation trajectory is low.

Before the Paris Agreement, the impact of high uncertainty on national inventories was addressed by the IPCC providing additional guidelines, training, and calculation tools. However, with the Paris Agreement, the respective national inventories became the basis for the design of mitigation policies and measures, as well as the departure point to track progress against commitments.

Caution should, however, still be used in comparisons or interpretation as, on a country level, forecasting of emissions, published and used by international entities, can vary significantly due to the use of different scopes, methods and underlying data. Countries that have ratified the Kyoto Protocol will calculate and publish their national GHG inventory at least every five years. The official data and estimations for China vary significantly from at least seven international entities' estimations for China.

These include entities such as the International Energy Agency[5] (IEA), BP, the U.S Energy Information Administration[6] (EIA) and the Climate Analysis Indicator Tool[7] (CAIT) of the World Resources Institute[8] (WRI). Song-Li (2014) recommends that China enhances its coal statistics, raises the frequency of official data publication, and improves the completeness of its emissions inventory. In another approach, GHG emissions data from Chinese provinces from 1984 were used to forecast a very different 2020 emissions trajectory (Auffhammer & Steinhauser, 2007). Like China, South Africa is a developing country, making extensive use of coal for internal energy requirements. In this paper, a similar evaluation to the Chinese evaluation of the underlying data, forecasts, and the emissions estimates is proposed for South Africa.

There is an increased focus on the evaluation of national policies that are expressed specifically in terms of only mitigating climate change, and not on energy, transport, urban planning or forestry. Although these have the effect of climate mitigation, unless they are explicitly linked to climate mitigation objectives they are not focused on (Dubash & Hagemann, 2013). With two or even three generations of national mitigation strategies in developed countries, there is still only a focus on bookkeeping of emissions, missing the opportunity to be a tool to pro-actively communicate and shape mitigation problems and solutions (Casado-Asensio & Steurer, 2015). This pro-active communication should stretch further than inter-ministerial progress reports and communicate action in the public domain.

The importance of tracking GHG emissions by countries also links to the risk of relocation of energy-intensive production from developed to developing countries (Babiker, 2005). GHG mitigation goals and associated policies in one region can lead to increased emissions in other regions, undoing the net benefit of achieving mitigation goals (Rogelj, Elzen, et al., 2016). This could be misleading when the mitigation actions are not reported together with the reduced inventory.

After the Paris climate change meeting in 2015, there was an agreement to reduce GHG emissions globally, but there is no internationally binding policy guidance on decarbonisation. Each country can develop their approach per sector, consistent with their respective development priorities. The proposed country trajectories should contain a sequence of sectoral changes in physical infrastructure, deployment of technologies, investment or consumption (Bataille et al., 2016).

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[5] www.iea.org

[6] www.eia.gov

[7] cait.wri.org

[8] www.wri.org

The global totals, made up of the submissions of individual countries, are however, impacted by at least six dimensions of uncertainty and could, therefore, vary between 47 100 $MtCO_2$ eq per year to 62 900 $MtCO_2$ eq per year, where the median emissions for 2030 is 52 300 $MtCO_2$ eq per year (Rogelj et al., 2017). The biggest global uncertainty contributor is the socio-economic trajectory of Asian countries (Rogelj et al., 2017). For Sub Saharan Africa it is not the projected socio economic trajectory, but the conditionality of the region's national commitments, that is a significant contributor to the uncertainties of the global emissions (Rogelj et al., 2017). With an uncertainty minimum and maximum range of 400-800 M $tonCO_2$ eq per year, this uncertainty dimension does not only filter through to the global totals but also through to decision making on a national and subnational level.

Although the current commitments made under the Paris agreements are not enough to prevent on average temperature rise of more than 2ºCelsius, the role of other stakeholders will increasingly play an important part in mitigation. However, the current mitigation contribution of non-state actors is unknown, even though research suggests a range of potential mitigation options. Commitments made at the New York Climate Summit, and published in Nature Climate Change found that these commitments could add 2 500 $MtCO_2$ eq per year, about one-fifth of the estimated emissions gap for 2020 (Hsu, Moffat, Weinfurter, & Schwartz, 2015).

The aggregated national commitments do not meet the Paris objective for the temperature target yet. The objective could still be met, however, as studies show that the commitments are conservative and the preparation of the NDCs has advanced national climate policy-making, notably in developing countries (Höhne et al., 2016 and Åhman, Nilsson, & Johansson, 2016). Recent studies on various possible pathways are exploring both sectoral and national trajectories towards an aggregated commitment that can meet the Paris objective (Bataille et al., 2016, van Vuuren et al., 2018, Goodwin, Brown, Haigh, Nicholls, & Matter, 2018)

Despite this positive outlook on increasing the ambition of national contributions, there is a relationship between cumulative carbon emissions and global warming. Some researchers indicate a linear relationship (Stocker, 2013). More recent analyses point to thresholds in that relationship (Rogelj, Schaeffer, et al., 2016), (Seneviratne, Donat, Pitman, Knutti & Wilby, 2016). Under the assumptions and scenarios made by the Oeschger Centre for Climate Change, keeping the global temperature increase below 2ºC would require emission reductions of almost 3.2% per year from 2020 onward. Even with this reduction trajectory, this model forecasts that the 1.5^{0}C target expires after 2028, and the 2^{0}C target after 2044 (Stocker, 2013). Delayed mitigation action or insufficient reductions will, therefore, require larger reductions initiatives later. The University of Oxford concluded that cumulative emissions of long-lived greenhouse gases, and particularly CO2, are a key determinant of peak warming, the consequence of being near the top of emissions in the allowable range for 2020 is reduced flexibility in emissions in 2050 and higher required rates of societal decarbonization (Huntingford et al., 2012). Improved carbon cycle models can also evaluate the warming caused by cumulative carbon emissions towards the trillionth tonne (Allen et al., 2009). However, this paper only considered the modelling and impact values of the IPCC fifth assessment report. If there is a threshold, or a larger threshold than projected by the IPCC fifth assessment report estimated, it will leave more time to take climate action or additional carbon budget for development and transformation. This paper assesses the historic and short to medium future, in tracking progress against medium range targets. Therefore adaptation or the impact of climate change in the regions was not considered.

2.3. The role of coal in greenhouse gas emissions and forecasting of developing countries

Unless large-scale drastic mitigation initiatives such as bioenergy combined with carbon capture and storage are implemented in the mid- to long-term future, the 1.5C limit is only achievable with a complete phasing-out of existing fossil fuel-based infrastructure within less than 20 years from now (Bataille et al., 2016). This requires shutting down a significant number of fossil fuel-based installations before the end of their life with significant associated costs (Höhne et al., 2016). A large number of developing countries rely on coal-based electricity generation. In China, India, and South Africa, for example, coal-based energy remains the primary source of GHG.

In India, in 2012, 60,6% of installed electricity generation capacity utilised coal, which equals 164,6 gigaWatt. Also, the sizeable coal reserves can, at the current consumption rate, continue to provide India with electricity for another one hundred years (Ministry of Environment Forest and Climate Change, Government of India, 2015).

In China, in 2015, coal contributed to 64% of energy consumed (China National Development and Reform Commission, 2016). However, the uncertainty of these values is reported as 5.2%, due to differences in coal classification and the respective calorific value of different coal types used (China National Development and Reform Commission, 2016).

2.4. Uncertainty in quantifying mitigation trajectories

Uncertainty in the emission inventory hampers the confidence in the trend of an emission trajectory. Only if the emission reductions are larger than the uncertainty of the reduction can there be confidence in the impact of the mitigation action on the overall emissions inventory. If assessing the cost-effectiveness of reduction is complicated in industrialized countries, this is exacerbated in developing countries due to resource constraints. Higher uncertainty is particularly acute with the non-CO_2 gases, as the uncertainty range for CO_2 is much smaller, estimated at 2-4% due to well-developed energy statistics and mature inventories. There was, however, a clear expectation that the uncertainty will reduce by 2010 (Rypdal & Winiwarter, 2001). The reason was improvement of inventories over time and chemicals being phased out under the Montreal Protocol on Substances that Deplete the Ozone.

This was indeed the case a decade later when in 2012, the European Union assessed the uncertainty of the GHG inventories of the fifteen member states for the 1990 to 2010 period (European Environment Agency, 2012). Although three countries, Austria, Netherlands and the United Kingdom reported reduced uncertainties (inventory excluding LULUCF), the uncertainties remain above 2%. These were the countries with the lowest uncertainties, below 3%. The tier 2 assessment of the European Union indicated that for CO_2 the uncertainty reduced from 2.0% in 1990 to 1.6% in 2010. Over the same period, the uncertainty in the overall inventory (including all gases) has also decreased slightly from 4.8% to 4.5%.

Under the Kyoto Protocol, the fifteen member countries of the European Union agreed to an 8% reduction of GHG emissions by 2012,from the 1990 level. As seen in the graph below the Kyoto target was met in 2009. Both the analysis and the target were linked to absolute emissions, with no clear reference to the mitigation initiatives implemented (Shishlov et al., 2016). Decoupling the emission reduction initiatives implemented from the GHG inventory does not provide an actual decarbonisation trajectory but reflects the low level of economic activity. During the 1990 to 2012 period, there was a significant decrease in the production of cement, iron, steel and adipic acid - as a consequence of the economic crisis. The combination of external and internal factors in the European Union did indeed result in a decline in absolute emission values as seen in figure 2-1 below, but this reduction did not require the implementation of 453 million tonnes CO_2 eq of emission reduction actions, but only reflected the impact of the reduced demand.

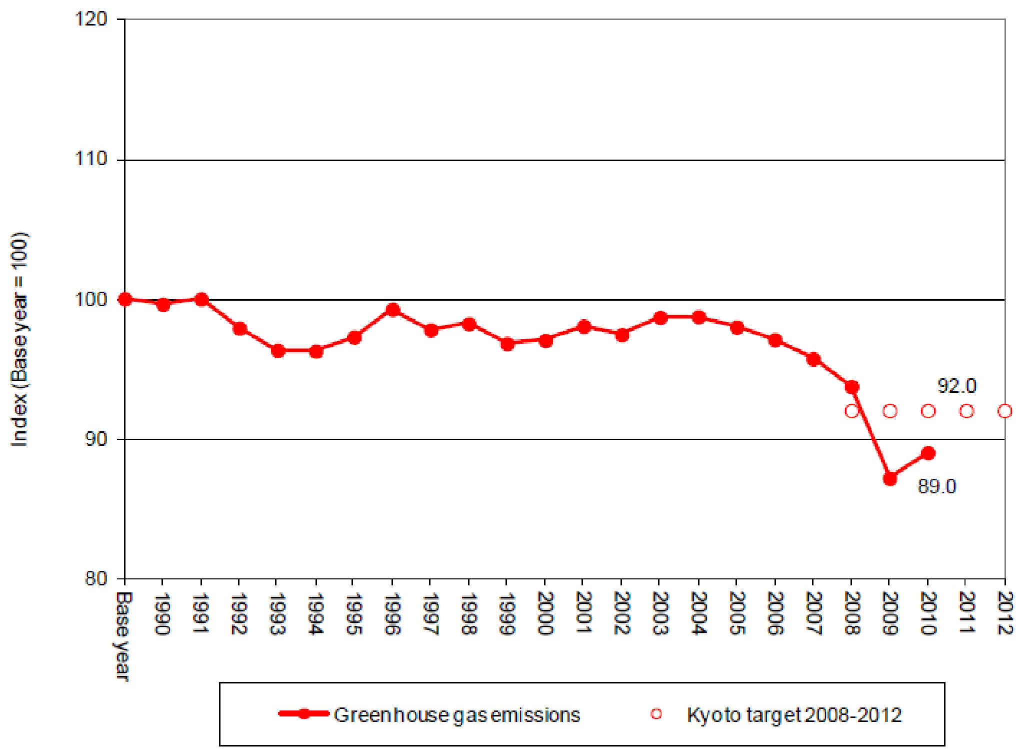

Figure 2-1 EU-15 GHG emissions 1990-2010 compared with the target for 2008-2012 (excl.LULUCF)

Source: Annual European Union Greenhouse Gas Inventory 2000-2010 and inventory 2012, Technical report 3/2012 page 8

With a reduction of 14,7% during the period 2008–2012, the European Union exceeded its 8% GHG emission reduction, as agreed to under the Kyoto Protocol (European Environment Agency [EEA], 2012). However, these reductions can only partially be traced back to mitigation policies in general and even less to specific mitigation plans or strategies (Casado-Asensio & Steurer, 2015). The reduction is due to the 2008 financial crisis (less demand), the lack of sufficiently documented implemented mitigation initiatives and the import of GHG intensive products (Shishlov et al., 2016).

For regions, such as Europe, and individual countries there is a difference between production and consumption related emissions (Aragon-Correa, Marcus, & Hurtado-Torres, 2016). Production based greenhouse gas emissions are the emissions countries calculate in line with the guidance by the IPCC and reported to the UNFCCC. These emissions include the emissions associated with the goods produced in the country. If, however, countries export a large percentage of the goods they manufacture, the greenhouse gas emissions embodied in the exported goods could be deducted from the inventory of the country to determine the consumption-based emissions of the country (Wiebe & Yamano, 2016). See chapter 2.11 on the implications and literature of consumption versus production accounting for national greenhouse gas inventories.

Uncertainty in the climate trajectories and a need for “early consideration of preventative measures” was already identified in 1986 (Laurmann, 1986). Later models of the IPCC confirmed both the need to improve the quality of input data and reduce the remaining underlying uncertainties (IPCC, 2007).

There is, however, a trade-off between environmental outcome and efficiency, as well as cost-effectiveness and incentives for participation and compliance (Aldy, Barrett, & Stavins, 2003). The resource constraint perspective already presented in 2013 indicate a strong correlation between resource availability and commitment to carbon mitigation and disclosure (Luo, Tang, & Lan, 2013). Unfortunately, this also holds true in times of economic downturn. One of the significant mitigation initiatives worldwide was the Clean Development Mechanism (CDM) that reduced emissions worldwide, including in South Africa. The CDM project pipeline slowed down due to a price collapse in 2012 and uncertainty in post- Kyoto demand. See figure below.

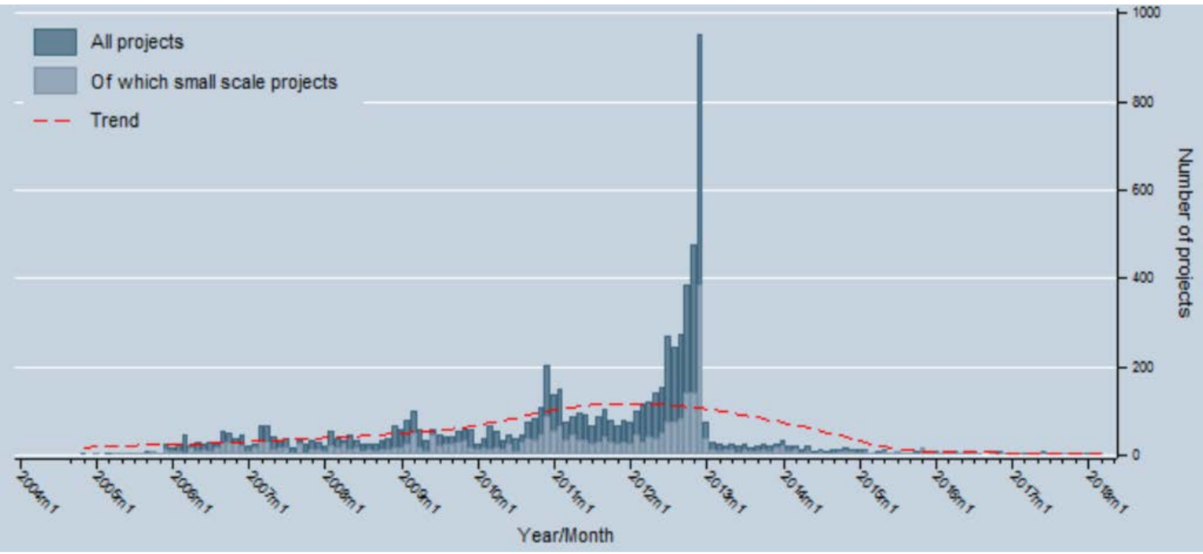

Figure 2-2 Registered and registering CDM projects

Source https://cdm.unfccc.int/Statistics

National governments are also not yet capturing the entirety of the mitigation commitments made by their subnational governments and businesses as there are limited systems in place to do so. In future, Article six of the Paris Agreement, which allows for non-state actors, including subnational action, will support the monitoring and reporting of all mitigation activities inside a country, not just those linked to government policies (Höhne et al., 2016).

Currently, national GHG inventories include all GHG emissions and removals taking place within national (including administered) territories as well as offshore areas over which the country has jurisdiction (IPCC 1996). While this definition seems reasonable, two key issues can be of concern (Peters & Hertwich, 2008).

Firstly, the IPCC definition differs from the system boundary used in the system of national accounts used for economic reporting. Therefore, the GHG inventory is not directly comparable to economic quantities such as GDP (Gravgård Pedersen and de Haan 2006). This difference gives rise to problems in allocating emissions from international activities.

Secondly, the IPCC definition is based on a country's production, irrespective of consumption, international trade or resource availability. As GDP is the monetary value of all the finished goods and services produced within a country's border, a related metric-the Gross National Product (GNP), would be more appropriate. GNP is the total value of all the final products and services in a given period using production owned by a country's residents. GDP, therefore, excludes international activities whereas GNP includes it.

Consumption-based national GHG inventories would be a possible solution. Several authors have discussed consumption-based GHG inventories: Kondo et al. 1998; Munksgaard & Pedersen 2001; Ahmad & Wyckoff 2003; Ferng 2003; Bastianoni et al. 2004; Peters & Hertwich 2006a, among others), but these methods, however, have not yet formed part of the implementation of the Paris agreement.

2.5. Reporting of GHG mitigation actions in South Africa

Focusing on South African academic literature relating to GHG reporting and forecasting, a strong bias to energy analysis and energy efficiency initiatives is revealed. Both the data and the analysis of these energy-related studies could be converted to GHG emissions and, therefore, benefit the climate change response topic. However, this seems to be lacking. For example, a sectoral decomposition analysis of energy consumption in South Africa, based on data from 1996 to 2006, shows that country-wide intensity changes could be misleading. The results are very sector specific and inter-sectoral differences are substantial (Roula Inglesi-Lotz & Blignaut, 2011). Over the period studied it was found that, in South Africa, the output (production) and energy consumption increased significantly while the efficiency improved (intensity decreased). The results imply that electricity consumption would have been about 120TWh higher if it were not for the slowdown in the increase of electricity intensity. For this paper, it is proposed to use the data published by Inglesi-Lotz and Blignaut in an ex-post analysis to evaluate the actual emissions baseline for South Africa (R. Inglesi-Lotz & Pouris, 2012). In a related paper, the CO_2 eq savings linked to electricity savings were unpacked, and it is argued that care should be taken with the changes in the grid emission factor over time (Harmsen & Graus, 2013). There are different ways to calculate the grid emission factor and the resulting grid emission factors can vary significantly (Spalding-Fecher, 2011).

With a focus on energy and energy policy in South Africa in various studies, such as those published by the Energy Research Centre (Harald Winkler, 2005) or the economics department of the University of Pretoria (R. Inglesi-Lotz & Pouris, 2012), the impact on associated GHG emissions is not explicitly explained. Only one study looked at this alignment (Tyler, 2010). The expansion of these studies towards the GHG emissions would add value to forecasting and target setting.

2.6. GHG reporting by energy-intensive sectors

The reporting of climate change information and impacts, especially by large energy intensive, and usually listed, companies, are typically done within various voluntary disclosure standards. The disclosure of climate change information has, therefore, been of interest to the accounting fraternity with substantive literature related to that of GHG reporting.

One of the drivers for voluntary disclosure is securing legitimacy. Disclosure can, therefore, be a pure act of symbolism for stakeholders, instead of actions (Hrasky, 2012). Voluntary disclosure and carbon accounting can also support democratic accountability for a functioning carbon market (Bebbington & Larrinaga-González, 2008) This is counteracted in the increase of disclosure under carbon norms (Pinkse & Busch, 2013). The verification of the disclosure response should also provide some comfort in the activity data and the historical GHG emission reductions reported. Verification, however, would not provide a measure of comfort on emission forecasts, nor on the targets set. As the CDP is an investor-driven disclosure programme, the information reported is limited to the specifications given in the template questionnaire. Studies done on the practical implementation of GHG data collection in Germany indicate that data is filtered and might be lost between the physical activity of collecting the data and the final analysis required for performance evaluation, decision-making, or securing legitimacy (Burritt, Schaltegger, & Zvezdov, 2011). As the information and analyses are filtered for specific users, the accuracy of forecasting, based on historical disclosure information, should be viewed with care. Another concern with voluntary reporting was raised upon a review of targets and performances of the UK’s supermarket sector, where the inconsistencies in company reporting on performances and outcomes make it lowers the confidence by stakeholders that the targets that were set have been delivered upon (Gouldson & Sullivan, 2013). Confidence of stakeholders are also eroded when accounting on different frameworks deliver different outcomes (Ascui & Lovell, 2011). Complexity and challenges in carbon accounting and developing GHG inventories is ultimately discouraging action in implanting GHG mitigation initiatives (Ascui & Lovell, 2011).

A review of public GHG emission disclosure through voluntary initiatives such as the Carbon Disclosure Projects (CDP) highlights the methodological differences that inhibit the usefulness of such reports (Andrew & Cortese, 2011). An interesting paper on the assurance of published GHG emissions touches on the uncertainties inherent in the assurance engagements for different industry sectors (Green & Li, 2012). This guides the interpretation of the published emissions data in this proposed paper as the proposed data had been assured annually since 2005. Assurance of the data is important as the confidence in the underlying data improves the confidence in the analysis of the results and associated data analysis. A useful content analysis of Australian listed entities regarding their carbon footprint disclosure focuses on the drivers behind the disclosure. It is found that carbon-intensive entities, in contrast with services based industries, have a longer-term strategy underpinned by real action (Hrasky, 2012). Similarly Hopwood (2009) identifies a need for critical and facilitated research and indicated that this need for demonstrating mitigation action would increase in the coming years as carbon emissions permitting could become a reality.

The burden of GHG reporting is lightened with easy-to-use guidance, such as those provided by the United Kingdom Department for Environment, Food & Rural Affairs (DEFRA) on GHG disclosure. Apart from a perceived lower burden the quality of voluntary disclosure also improved (Tauringana & Chithambo, 2015). With a sample of 215 companies from a population of London Stock Exchange FTSE 350 companies (from 2008 to 2011), the disclosure improved as much as what it would do with mandatory reporting. Standardised reporting guidance also reduces uncertainty (Rypdal & Winiwarter, 2001).

Energy-intensive companies operating on a global level have produced carbon-disclosure reports using such a variety of methodologies, that comparability is difficult (Andrew & Cortese, 2011). It is especially difficult to deal with investments and mergers in these disclosure reports.

The South African energy efficiency accord, as a voluntary agreement between government, industrial energy users and industrial organisations, is internationally seen as a good illustration of how emerging economies are mobilising private investment in energy efficiency (Ryan et al., 2012). Although this accord does include a financial incentive for participating companies in the form of a tax benefit associated with the energy efficiency, it was only put in place in 2014. As the accord was designed for the 2000 to 2015 period, the overall benefit received from this financial incentive was limited. From the signatories of the energy efficiency accord, there has, therefore, been limited public reporting of progress-to-date, and the methodologies to evaluate performance have only recently been developed. The signing of the accord was, however, important in itself, as it was the start of formalising energy reduction plans and projects and setting GHG targets for some large energy consumers. The industrial sector, which includes mining, is the largest consumer of energy and electricity in South Africa, with the mining sector consuming approximately 20% of electricity in South Africa (Department of Energy, 2009). Therefore, it is not surprising that 10 out of the 24 signatories to the energy efficiency accord were mining companies.

Using the information on energy efficiency improvements available, either within entities or in the public domain over the last decade, provides valuable insight into the reporting of GHG forecasts and targets, as well as evaluating the options to track and present progress over time. The academic literature provides good coverage regarding electricity saving opportunities or projects (Fraser, 2008) (Marais et al. , 2009), but fails to address the impact on GHG emissions. The impact of these projects, especially cumulative energy savings, could be significant on the overall GHG inventory and provide the evidence to further support this type of mitigation initiatives. Combining these initiatives in an integrated emission target framework would further support the transition to a low carbon economy.

2.7. GHG reporting in the mining sector

The use of publicly disclosed GHG emissions data, especially from the mining sector, is sound. This is supported by the work of Rankin et al. (2011), which concludes that companies that disclose credible information are more likely to be large and in the energy, mining, industrial or services sectors. Although the research focused on the Australian sector, the principles are the same for similar companies world-wide, as it is linked to the existence of an internal Environmental Management Systems and adherence to the voluntary reporting guidance such as GRI or CDP (Rankin, Windsor, & Wahyuni, 2011). These companies are also more likely to have the projects and underlying baseline GHG emissions to apply for carbon credits, that can be traded under the various carbon schemes and related carbon markets. Under these carbon schemes, verification of GHG data is prescribed and research designed to provide a high level of confidence in the reported data.

This view is supported by another study on the Australian mining companies that indicates a strong correlation between meeting environmental improvement targets (including GHG reductions) and increased stakeholder communication (Gomes, Kneipp, Kruglianskas, Da Rosa & Bichueti, 2014). The reason for Australian mining companies to disclose GHG inventory data is to ensure their social licence to operate (Pellegrino & Lodhia, 2012). However, it was concluded that GHG inventory disclosure should be only the first step towards appropriate climate change response and should be matched with reporting of associated actions to reduce the carbon footprint (Pellegrino & Lodhia, 2012).

Information about specific mitigation actions, either proposed or implemented, is unfortunately not as widely covered in the literature as what would have been expected for the mining sector. This energy intensive sector is most vulnerable to an increased cost of energy and increased pressure to reduce GHG emissions, and, therefore, widespread adoption of GHG mitigation actions would be beneficial. Case studies, such as variable water flow in deep level mine cooling systems (du Plessis et al., 2013) and optimised water reticulation in deep level gold mines (Vosloo et al., 2012) or improving fan blades to reduce energy consumption (Panigrahi & Mishra, 2014), could be replicable across the industry. The options of the mitigation actions for effective GHG reduction have been identified for the iron and copper industries respectively (Norgate & Haque, 2010). Where the iron industry could benefit from a focus on loading and hauling, the copper industry should focus on reducing the GHG emissions associated with grinding (Norgate & Haque, 2010).

Sector-specific conference proceedings contain useful case studies, data or feedback on energy-saving initiatives implemented on a pilot scale, with detailed data sets. Conferences such as those organised by the Southern African Institute of Mining and Metallurgy, therefore, play an important role in disseminating information about mitigation actions. Specific examples are in the reduction of compressed air use (Fraser, 2008), documentation of compressed air leakage solutions (J Marais et al., 2009), the impact of DSM projects on overall energy consumption (Lodewyckx, Kleingeld, & Pelzer, 2008), or meeting the reduced availability and rising costs of electrical power through ventilation and cooling strategies (Biffi & Stanton, 2010). There is, therefore, a need to present the emission reductions from these mitigation actions as a contribution to overall emission reduction.

Similar to GHGs, the achieved energy savings is important in assessing and evaluating the success of projects. Marais et al. (2011) concluded that external factors beyond the scope of the projects influenced the energy consumption related to compressed air in their mining case study. Their solution was scaling of the baseline based on production and although it is a valid approach, it does not apply to situations where the production does not correlate well with the energy consumption (JH Marais, Kleingeld, & van Rensburg, 2011). Although very useful actual data and correlations are presented, the solution to correct the baseline over a period by deactivating the energy saving project might not be practical for most other applications. This lack of correlation, between production and energy consumption, would be especially visible during the development phase of underground mining levels or stripping of overburden in a new opencast mining area.

2.8. GHG emissions and mitigation actions by cities

At a local level, both companies and cities are increasingly recognised as key stakeholders for mitigation actions. An analysis on a city scale level (Hunt & Watkiss, 2011) highlights the need to make climate change risks and opportunities more relevant to private and public agents who need to design and implement possible mitigation actions. An actual baseline and visualisation of the impact of the mitigation actions might, therefore, assist in making the relevance clear. Another tool developed for cities is a typology of urban-scale emission-reduction technologies and practices (Erickson, Lazarus, Chandler & Schultz, 2013). This tool identifies policies and measures that can support the adoption of these technologies and practices and can assess their relative abatement potential in the nearer (2020) and longer (2050) term, while examining the degree of influence of urban jurisdictions on realizing these potentials.

Central government provides climate change policies and priorities, and even indicators that guide the focus of climate action on the sub-national level (Cooper & Pearce, 2011) In the United Kingdom these were implemented and used to commit to targets on a sub-national level. Targets to reduce per capita CO_2 emissions in the local authority area were twice as likely implemented than targets to reduce CO_2 emissions from local authority operations (Cooper & Pearce, 2011). Apart from a diverging methodology for GHG accounting on a local authority level, it is shown that about 60% of mitigation was also attributed to national measures and the remainder through local government's influence and measures (Cooper & Pearce, 2011). Although this study is conducted in the UK and not repeated in a developing country context, the lack of capacity and budgetary constraints identified, on local government level, is an important factor in straining climate action. An interesting quote from a local authority interviewee stated that due to the time delay in national emissions data " the most important thing is the action plan, what you're doing, rather than whether the national indicator had gone up or gone down" (Cooper & Pearce, 2011). Disclosure of mitigation action is inhibited where it becomes difficult to measure and account for climate change performance on a local level. It is not always clear where and with whom lies control and accountability, and this constraints quantification and disclosure.

A study on climate action by the local authority in Queensland, Australia, concludes that climate action strongly relates to council size, capacity and climate change strategies (Zeppel, 2013). The study also found that climate mitigation actions are mainly implemented in cities, then regional and lastly shire councils. Carbon leadership is, therefore, mainly evident among larger councils (>30,000 population), that have climate change plans and targets. (Zeppel, 2013).

In South Africa four metropolitan cities contributing more than 20% each to national Gross Domestic Product (GDP) (*Community Survey 2016 Statistical release*, n.d.). GDP per capita is a measure of a country or city's economic output that accounts for its number of people. That makes it a measurement of a city's standard of living. These cities also form part of the Global Covenant of Mayors for Climate and Energy, and are actively involved with in the the voluntary global network, the C40 initiative (www.c40.org). The C40 is a global network of large cities taking action to address climate change by developing and implementing policies and programs that generate measurable reductions in both greenhouse gas emissions and climate risks. These cities are committed to develop GHG inventories according to a common methodology, set targets and implement climate mitigation initiatives (*The Compact of Mayors Goals, Objectives and Commitments*, 2014) .

Data about mitigation projects on a household level in South Africa is very limited. Only one example was found, linked to solar water heaters. The total thermal demand for the next 20 years for water heating technology in South Africa is estimated as 2.2EJ, with 98% of this potential in the residential sector (Donev, van Sark, Blok, & Dintchev, 2012). The implementation data on household solar water installations per city is available through a national provincial survey by the Statistics South Africa (Statistics South Africa, 2018b).

2.9. Alternative benefits associated with environmental reporting and GHG reductions

Two local studies evaluated GHG emission reductions as a co-benefit to sustainable development initiatives. Winkler et al. (2007) presents the implications of South African industrial energy reduction initiatives on sustainable development in the form of costs, pollutants and employment opportunities. In addition to sustainable development benefits, Tyler (2010) evaluates the alignment of South African energy, climate change and mitigations policies to support sustainable development, while Labuschagne et al. (2005) revises the criteria of corporate sustainability reporting within the developing country context.

Corporate carbon accounting is playing an instrumental role in informing societal and political institutions and, therefore, in supporting decision-makers in designing regulations and international agreements. Nearly a decade ago Hopwood (2009) identifies corporate environmental reporting as an area that needs research. During the same period Burritt et al. (2011) evaluates Corporate Carbon reporting by German companies over a two-decade period. Both concludes that although the data is collected and reflected as per the requirement, there is a lack of purpose when utilising the data to improve carbon management or long-term sustainability of the companies (Burritt et al., 2011). In contrast Schaltegger and Csutora (2012) conclude that the mitigation of carbon emissions by corporations is of high relevance for sustainable development, as well as an increasingly important business topic itself (Schaltegger & Csutora, 2012). With a focus on minimising cost, while the benefit is unknown, it is difficult to develop a business case for investment in data collection or to implement mitigation actions itself.

There is a gap in communicating GHG inventories, mitigations and related benefits. This is partly due to the different types of carbon accounts used in scientific, political, economic and corporate arenas, which are still evolving. They are related but are not properly interlinked in policy or strategy.

The ex-post model might assist in demonstrating the benefit through tracking progress and visually presenting the impact of the GHG mitigation actions. Additional research is needed to support the effective and efficient implementation of low or zero carbon solutions, and related sustainable development.

2.10. GHG target setting and mitigation goals

GHG target setting can take various policy forms. Under the current international climate change negotiations, countries might propose respective national GHG emission targets, such as in South Africa, or focus on domestic goals only, such as in China and India (Bailey & Compston, 2012). Both these types of targets would be considered as a commitment, that could lead to real overall GHG mitigation. The South African initiatives around the Energy Efficiency Accord is both a national commitment, for establishing the incentive schemes, and a company-specific commitment, for reducing GHG emissions below a baseline (Tyler, 2010). The performance of the South African mining industry against this commitment can be evaluated, as the timespan of this commitment has lapsed. No reports or consolidation has to date been published.

The availability of resources directly impacts on and, therefore, can restrict climate action, with respect to both disclosure and mitigation initiatives (Luo et al., 2013). This will impact on commitments of both companies and countries, differentiating developing and developed countries and the companies operating in those countries. In Canada, the public support for fossil fuel taxes decreased significantly with the increase of gas prices and deteriorating economic conditions (Milne & Kuntz, 2008).

Carbon markets can also be an effective tool for mitigation. MacKenzie (2009) evaluates the design and the accounting associated with carbon markets, emission reductions, and GHG permits. For the purpose of this research, GHG permits is seen as a GHG target, as the mitigation action is well defined and the GHG reporting verified and it is in the public . This is similar to the sector or company level emission targets for industrial energy use or GHG reduction, linked to 50 different emission permit systems in the Netherlands (Rietbergen & Blok, 2010). Furthermore, in forecasting emission savings, care should be taken with the methodology, as the CO_2 intensity approach cannot be used to estimate future electricity savings (Harmsen & Graus, 2013). It is questioned whether companies' GHG targets can be relied on by policy makers and other stakeholders, as companies do not have to deliver on these commitments (Gouldson & Sullivan, 2013). The relative trust that governments can have in the mitigation by individual companies, individual or collective, depends on the level of transparency of reporting and the setting of an appropriate baseline (Gouldson & Sullivan, 2013). The principles proposed to improve the performance and outcome is used in the ex-post analysis analytical technique.

Studies on the best practice environmental sustainability indicators have shown that it is important to set targets and to assess the distance to the target to get the appropriate information on the current state (Moldan, Janoušková & Hák, 2012). However, in a data-poor environment, this would only be possible if both the current inventory and the mitigation action are presented together.

On a long-term global scale, GHG emissions, based on fossil fuel use estimates, until 2050, with the same input data as that used by the IPCC, results in similar trends but different outcomes (Schmalensee, Stoker & Judson, 1998). The authors use a flexible form for income effects, along with fixed time and country effects, while forecast uncertainty is explicitly handled. Therefore, the GHG emissions growth projections exhibit significant and substantial departures from widely used IPCC emission projections. In a similar long-term mode, research indicates that as mitigation is delayed, emission reduction targets become unachievable (Stocker, 2013). Comparisons of projections from 1990 against actual, observed climate trends show an increased climate response, which is of concern for the current requirements of feeding and housing human civilization. There is even interest in publishing regional changes in climate extremes instead of changes in global mean temperature, in order to convey their urgency better. (Seneviratne, Donat, Pitman, Knutti & Wilby, 2016). Although that might be seen as alarmist, it does indicate the increasing interest around climate change response and the need for sound and scientific emission tracking and target setting on company, sector, and national levels. Especially where commitments of GHG reductions are done in parallel with maintaining commitment of constructing new fossil fuel based energy installations, the overall benefit can be small, or non-existing. The planned new fossil fuel energy installations, are increasing the GHG emissions associated energy at 4% per year (Davis & Socolow, 2014). The authors establishes that this fact is not well known in the energy policy community, as annual emissions receive far more attention than future emissions related to new capital investments (Davis & Socolow, 2014).

A Korean study of particular interest, as it covers both historical baselines and performances against targets, find that where demand is not factored into the GHG emissions target the entities could not meet the set goals (Lee et al., 2013). This would, therefore, be an ideal application of the ex-post analysis where the reduced demand is separated from the emissions reduction activities. Also, this would be valuable input for testing the ex-post analysis on the GHG performance of South African mining companies.

2.11. Philosophical challenges and limitations of greenhouse gas reduction targets

There is no direct experiment possible for the carbon-constrained future of either 2°C or 1.5°C, or the real impact of a high emissions scenario on our planet. The evidence, however, indicates that a carbon-constrained world would be able to support a sustainable society. The concern from a philosophical perspective is that such a sustainable society would be underpinned by new economic principles and a radically different worldview that informs policies, institutional frameworks and practices (Bernier, 2014). Politically, as well as philosophically, concerns with human rights and social justice forms part of the worldview for a sustainable future (Caney, 2009). Planning for such a future from both a company and city perspective, within the current short, medium and long-term sustainability strategies is not easy. There is, therefore, a growing interest in performance metrics and the role they can play.

On a country level, another aspect that requires consideration is production versus consumption related emissions (Aragon-Correa et al., 2016). Production based greenhouse gas emissions are the emissions countries calculate in line with the guidance by the IPCC and reported to the UNFCCC. These emissions include the emissions associated with the goods produced in the country. If however countries export a large percentage of the goods they manufacture, the greenhouse gas emissions embodied in the exported goods should be deducted from the inventory of the country to determine the consumption-based emissions of the country (Wiebe & Yamano, 2016). This would link the country emissions to the average consumption of the citizens in the country. While consumption-based emissions and production based emissions are for the majority of countries within 10% variance, there are countries with very little production but high consumption patterns, as well as resource-rich countries with little local demand, and thus lower consumption-based emissions. These extremes should be addressed in target setting methodologies to provide businesses operating in these countries a practical greenhouse gas target related to the standard of living and needs of the country.

Many arguments have been made for and against consumption-based greenhouse gas accounting (Afionis, Sakai, Scott, Barrett, & Gouldson, 2017). However, in the absence of international carbon pricing scheme, consumption-based greenhouse gas accounting would allow consuming countries to share the cost burden for greenhouse gas emission reduction of producing countries. This ensures that the population of a country is responsible for the emissions, and the reductions thereoff, related to support their lifestyles and not that of other countries.

Greenhouse gas emissions are predominantly linked to global population numbers, affluence levels, and consumption patterns. Each of these is difficult to change with regional or local policies, and cannot be influenced by individual companies. On the other hand, the energy and process related greenhouse gas emissions for products and services for use in communities, and to sustain affluence levels, are directly or indirectly under the control of individual companies. While there are good reasons for reducing greenhouse gas emissions, there needs to be decisive actions to avoid dangerous climate change (Bernier, 2014). The current worldview and business practices have enabled a high carbon society that is putting climate stability at risk. To date, carbon constraint has not been a key driver nor has it influenced company strategies. Long-term corporate sustainable strategy development has not taken planetary boundaries and limitations into consideration, but will have to balance providing employment and economic growth on the one hand and decarbonising the business on the other (Schaltegger, Lüdeke-Freund & Hansen, 2016), (Whiteman, Walker & Perego, 2013). The challenge is to move towards a sustainable future, that is not well defined (Biely, Dries Maes, Steven Van Passel, & Biely katharinabiely, 2018). This can also be presented as a careful balance between strategic positioning and constrains, including stakeholder influence against carbon dependency (Pinkse & Busch, 2013).

How the sustainable future would look for a company would depend on the current values of the employers, the employees, the company, and the society it operates in. However, with values plotted on a bell curve, the majority of people are "pragmatists" interested in acting on their values within the constraints of a business context. Only on the tail end of the curve are "idealists" with a strong but less realistic moral compass, and the "opportunists" , the small group of people that value self-interest above all else (Gentile, 2012), (Painter-Morland & Slegers, 2017). It is not clear where on the bell curve the leadership of a company must be positioned to drive or enable a radical change in management philosophy for the far future within the planetary constraint. Especially in setting long-term GHG emission targets and adapting the company to survive, or thrive, in a low carbon future would require a transformation in the business model and management practices, and more than just support from the leadership. An example of positive climate change action that was not yet transformational, is the initial climate change strategies of supermarkets in the UK which were underpinned by the philosophy that efficiency and continuous improvement will be sufficient. This did result in achieving some emission reductions, but was not transformational, and none of the retailers were considering radical changes in their business models (Gouldson & Sullivan, 2013). A long-term target for GHG emission reductions would be a tool for radical and transformational change, not just in product design, but also of the overall business model of a company. (Bovea and Pérez-Belis, 2012). A single metric of setting a target will not be the only area to drive transformational change. It will require a drive in the change to the business strategy to achieve this target. By only setting a target, transformation change will not be achieved.

The role of greenhouse gas targets for companies would be to assist in defining the future of companies within a limited and shrinking carbon budget. This has to be done in an ever-decreasing timeframe, possibly by 2020 (Figueres et al., 2017). While it is good to move from a reactive response to environmental threats to the development of a more proactive business strategy, the pace of climate change and associated ecological problems are increasing (Whiteman et al., 2013). The pace of action should also speed up accordingly. Discussions about greenhouse gas targets can stimulate discussions about technologies, renewable energy potential and production efficiency. This is essential in identifying a company's emission reduction potential, resulting in transformational thinking and change to the overall business strategy so that these targets are achievable.

Currently, companies participate voluntarily in the achievement of a below 2°C global trajectory, by following any methodology for target setting, participating in any target setting scheme, or implementing any GHG emission mitigation actions. Setting a target is an environmental choice. Companies make environmental choices based on one of three factors: regulatory frameworks, internal capability, or linkages with shareholders (Aragon-Correa et al., 2016). In the case of GHG targets, the driving factor towards participation in the setting of targets is from pressures by the shareholders or investors who encourage business improvement and efficiencies, as well as environmental consciousness. In the case of listed entities, over the last fifteen years, the CDP initiative has placed increasing value on the setting of short-, medium-, and long-term GHG targets that are in line with a long term global mean temperature that does not exceed 2°C. This reporting initiative has seen an increase in the number of companies setting GHG emission targets, and an increase in the reporting of these targets in the public domain. This is in line with the balanced scorecard thinking, where concerns on a macro level of society are translated into a number for company-based leadership to manage performance (Bento, Mertins, & White, 2017). However, this has not necessarily resulted in a decrease in GHG emissions or transformational change within the business. There is an increasing interest in developing performance metrics beyond finance, such as achieving a GHG emission target (Searcy, 2012),(Dahlmann, Branicki & Brammer, 2017),(Ioannou, Li, & Serafeim, 2016), (Maas & Rosendaal, 2016).

Developing GHG targets can result in a transformational change of the business strategy in the short-, medium- and long-term, but to set meaningful GHG emission targets, would require the identification of reduction potential within a company, or within a company's sphere of influence. As such, targets on their own cannot achieve transformation change within a company. Targets that can result in transformation change would also require an understanding of the resources available. Budget is needed to make progress towards meeting a target, as well as for providing technical competency for implementation of these actions. Similar to technological change, the transformational change would require allocation of resources (Christensen & Bower, 1996). Setting and delivering on these targets would require commitment from management and the leadership of the company in order to transform the business strategy so that it is in line with the GHG target. Setting such a GHG emissions target, however, is in itself not transformational, nor an indication of emission performance. As an example, a company with a large target could be the reflection of inefficient performance to date, instead of an ambitious commitment to change its emissions trajectory. However, a performance metric linked to a GHG target can be a tool to drive radical change within a company as opposed to radical change itself (Bovea & Pérez-Belis, 2012). Change does not happen simply because a company has a metric or a tool. Without an analytical tool, however, progress against targets is difficult to communicate.

2.12. Conclusion

This literature review indicates a gap where the evaluations of actual mitigation initiatives are not clearly compared to forecasts and, therefore, the implications for target setting are not articulated. This seems to be relevant within various contexts, such as a company, sectoral, and city level. Although emission reduction technologies and initiatives are covered in the literature, the lack of further interrogation of the GHG emission results reduces the overall benefits of these standalone analyses. With the lack of integration of these concepts, target-setting becomes more political than analytical. In addition, where there is an expectation that targets should be met, tracking progress towards these GHG targets becomes important.

The next section outlines the methodology to develop an appropriate analytical technique, and the various applications.

3. Methodology to develop the ex-post analysis technique

3.1. Introduction

In order to examine how the GHG reporting supports effective target setting or tracking of performance progress against climate change targets, a qualitative research approach is used with multiple case studies (Yin, 2003),(Bloomberg & Volpe, 2016). The three case studies, namely national, company-specific and cities, all in South Africa, are used to demonstrate applicability and transferability of the ex-post analytical technique.

The ex-post analytical technique is developed for each application in two stages. First, historical GHG inventory data is analysed regarding the boundaries, the data gaps, and metrics. This enables the restatement or recalculation to compensate for data gaps in terms of time series, activity or emission factors. The forecasting trajectories are analysed in general for the direction of the trends and the GHG metric in particular. Climate change commitments or targets, publicly declared, can take several forms and these are analysed. The implemented mitigation initiatives within each application are explored and then quantified. This provides the basis for the second stage of the research, which involves the application of the analytical technique by adding the mitigation actions to the emissions trajectory in order to evaluate progress against emission reduction targets.

The application of the ex-post analytical technique within three different contextual settings highlights the complexity of GHG reporting and target setting in a developing country, which would not be possible with a quantitative research approach. The purpose of the case studies is to provide a more nuanced trajectory of performance against targets and commitments using the ex-post analytical technique. The following three aspects are explored:

- How key indicators and careful boundary setting can improve emission forecasting,
- Whether transparency is appropriate and valuable, and how it can enhance climate action and target setting, and
- Why mitigation actions should be quantified and added to the emission trajectory to support GHG forecasting and target setting.

3.2. Development of the analytical technique

The interaction of the various concepts provides the basis for constructing an integrated analytical technique. Therefore, the quality of the underlying methodologies and guidelines to the various concepts also supports the overall quality of the results when applying the analytical technique.

3.2.1. Greenhouse gas inventories

The GHG Protocol[9] has developed an accounting and reporting standard for estimating the GHG effects of policies and actions. The GHG Protocol is a partnership of businesses, governments, academic institutions, and others, convened by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). This standard was developed in 2013 through a global multi-stakeholder process, and the analyses were initiated as a pilot project to test and verify sections of the standard.

The *Policy and Action Standard* provides guidance to evaluate GHG performance. The starting point, according to the guideline, is the choice of a historical base year. Selecting a historical base year would either be a default year, such as 1990 if linked to the Kyoto Protocol, or 2000 if linked to the South African GHG inventory (Department of Environmental Affairs Republic of South Africa, 2013a). Alternatively, the base year would be the first year for which reliable data is available. Although the Energy Efficiency Accord suggests the year 2000 as the base year, information is only available from the date of becoming a signatory and, therefore, the 2005/2006 financial year is often taken as the base year for the respective analyses of the mining companies in this study. For South African cities the authoritative statistics are contained in the National Census of 2011.

The *Global Protocol for Community-scale Reporting* methodology is used by most cities as part of either the CDP Cities or C40 (WBCSD/WRI, 2014). The Greenhouse Gas Emissions Interactive Dashboard (GHG Dashboard) and associated data are made available for public use as part of the C40-wide initiative to improve the accessibility and transparency of public data reported by C40 member cities ("C40 Cities Climate Leadership Group," 2017). The access and use of the data are linked to the C40.org's Terms of Use and under the CDPs open data portal license. The primary source of the data in the dashboard is from GPC compliant GHG emissions inventories and target information reported by C40 cities. The data quality is linked to a review by C40 to confirm all inventories are GPC compliant. In addition, the main source of data and responsibility for data quality remains with the individual cities

[9] www.ghgprotocol.org

In accordance with the WRI standard, after selecting a base year, the published GHG emissions and intensity factors are evaluated. For this research, only publicly available emissions and intensity factors are used. The top 100 companies listed on the Johannesburg Stock Exchange (JSE) are voluntarily participating in the Carbon Disclosure Project[10]. As part of this initiative the GHG emissions inventories of these companies are publicly available, usually verified, and either published in standalone reports or consolidated in the company annual reports. These GHG emissions inventories include, as a minimum, both direct (Scope 1) and energy indirect (Scope 2) emissions.

3.2.2. Forecasting of greenhouse gas emissions

Forecasting of emissions is linked to the key planning metrics in each entity. For mining companies, the key planning metrics are also reported as performance metrics in annual reports and commonly used internally for benchmarking and forecasting. The two metric types typically used in mining companies are either based on operations, such as tonnes milled or mined, or are based on production volumes, such as ounces of gold or tonnes of iron ore.

The metric for national GHG emission forecasting is linked to economic growth and sector-specific policy implementation. Economic indicators can be used as a proxy for activity data in a sector such as energy consumption for energy production, population figures for waste generated and manufacturing production index for industrial production as well as liquid fuels produced for liquid fuels consumed.

The metric for city planning is population growth, as GHG emissions are predominantly linked to population numbers, affluence levels, and consumption patterns. The national statistics in South Africa has, to date, two authoritative sets of population records per metropolitan city. These are the 2011 National Census, published in 2013 and the 2016 Community Survey, published per province in 2018 (Statistics South Africa, 2013),(Statistics South Africa, 2018a),(Statistics South Africa, 2018c),(Statistics South Africa, 2018b). The National Treasury publishes growth forecasts for Gross Dometic Product and estimated 2020 population value for each city in South Africa (National Treasury, 2017) .

Local government in South Africa is largely understood in terms of service delivery and the South African constitution (Act No. 108 of 1996) assigns municipalities the role to mobilise economic resources towards the improvement of the lives of all citizens. Free basic services is the term for a basket of four basic services: water, electricity, sewerage and sanitation, and refuse removal that poor households get for free, and statistics around basic service delivery is published by Statistics South

[10] www.cdp.net

Africa (Statistics South Africa, 2017b). With the national commitment in 2016 of working towards meeting the needs of the citizens under the sustainable development goals, the GHG emissions for the cities are adjusted accordingly based on the data from the Community Survey 2016 (Statistics South Africa, 2018b).

Forecasting of GHG emissions is uncertain and is based on a range of assumptions. Therefore, the outcome for each application is evaluated against the criteria of evaluating forecasting alternatives. According to the Canadian Round Table on the Environment (Page, Francine, Benjamin, & Browes, 2008), the four main criteria for evaluating the best forecasting alternatives are:

- Past accuracy,
- Sound representation of the current system,
- Enough transparency to review the underlying assumptions, and
- The ability to conduct sensitivity analysis.

3.2.3. Climate action and mitigation projects

To determine the change in GHG emissions resulting from a given action, a reference case should be established, which represents conditions that would most likely occur in the absence of mitigation actions. This is referred to as the counter factual baseline, also termed business-as-usual, from which the impact of GHG mitigation actions can be calculated. The disclosure of mitigation actions and targets has changed over time as the Carbon Disclosure Project has changed the questionnaire every year. Only the disclosure of the GHG inventory remained consistent over time. Mitigation actions can be calculated based on reduced activity data and appropriate emission factors. Where the mitigation action is the basis for a carbon credit project the monitoring and verification of information is in the public domain and of high quality. The methodologies for calculating emission reductions have undergone a rigorous process but could be conservative, meaning that the actual emission reductions could be higher.

For reductions on both a national level and city level, two assessments commissioned by the Department of Environmental Affairs are used. One for the impact of the waste management strategy (Shachar, Pretorius, Fourie, Couperthwaite, & Smith, 2016) and the other for the impact of the national transport strategy (CSIR, 2016). Additional mitigation actions are obtained directly from the UNFCCC CDM website as well as from the national climate change response reports (Department of Environmental Affairs Republic of South Africa, 2016), (Department of Environmental Affairs Republic of South Africa, 2017). The national utility Eskom, as a parastatal organisation, is legally required to verify the information in their annual reports, and, therefore, the mitigations actions, as well as the Demand Side Management initiatives of the country, can be accessed at a single point (Eskom, 2016a), (Eskom, 2017). The South African Petroleum Industry Assessment, SAPIA, collates production data for the Department of Energy, and it is also independently published in annual reports (SAPIA, 2015).

3.2.4. Greenhouse gas target setting

The GHG target setting is explored in terms of the mitigation goals standard of the WRI (World Resources Institute, 2014a) that provides guidance on the technical aspects of goal design and assessment. Setting GHG reduction goals is a political process, and the way a goal is designed will depend on national or city objectives, circumstances, capacities, available support, as well as other considerations about feasibility.

Companies worldwide are increasingly required to set targets for the reduction of their carbon footprints. This is especially true if the company in question participates in the disclosure of its GHG emissions and climate change actions through programmes such as the CDP.

As the tracking of progress against existing targets, or reviewing new targets, are the focus of this research, the targets that are used are publicly disclosed, but classified against suitability within one of the four categories of targets as shown in Table 3-1.

Table 3-1 Overview of mitigation goal types

Goal type	**Description**	**Reductions relative to what?**
Base year emissions goal	Reduce, or control the increase of, emissions by a specified quantity relative to a base year.	Historical base year emissions.
Fixed-level goal	Reduce, or control the increase of emissions level in a target year.	No reference level.
Base year intensity goal	Reduce emissions intensity (emissions per unit of another variable, typically GDP) by a specified quantity relative to a base year.	Historical base year emissions.

Baseline scenario goal	Reduce emissions by a specified quantity relative to a projected emissions forecasted baseline.	Projected baseline scenario emissions.

Source: *Mitigation goals standard* of the WRI (World Resources Institute, 2014a)

4. Application of the model at a national level

4.1. Introduction

To develop the analytical technique, the GHG emissions data for South Africa is reviewed from official published emissions data, and complimented with data provided in other national statistics and publicly available energy reports. The existing 2010 GHG inventory for South Africa is extrapolated with a bottom-up calculation, using coal calorific values reported by Eskom, the electricity utility of the country. The International Energy Agency and South Africa have undertaken a wide range of co-operation projects and are working together in the field of data sharing, and, therefore, energy data from 1990 to 2014 is available in the public domain. The single largest GHG emission source to the GHG inventory is the coal-based electricity generation.

Bridging the period between the published 2010 inventory gap and the present (2011 to 2016) requires the estimation of the national emissions trajectory. The current estimation of emissions is done from statistical trade data, using 2010 national inventory (excluding forestry and land use categories) as the reference case for percentage contribution to the national inventory. The growth of the three IPCC key categories is assessed based on the changes in the national statistics. The waste category is changed in proportion to the population growth. The monthly national industrial production information is used as a proxy for the Industrial Product and Process Use (IPPU) category. The energy sector is separated into electricity and non-electricity generation to represent the emissions from the coal and liquid fuel consumption data. The coal volumes, calorific values and electricity consumption data are obtained from the audited annual financial reports of the state-owned electricity generator, Eskom. The official petroleum product consumption statistics are used to estimate the transport emissions.

There is an overarching challenge of both data availability and data quality in developing countries such as South Africa. Tracking progress towards a lower carbon economy is hampered by this challenge.

Four steps are taken to overcome these barriers and allow for tracking of the South African low carbon transformation in one climate action infographic:

- Correcting the 2000 to 2010 emission inventory that is submitted in the public domain, based on coal calorific values used for electricity generation,
- Estimating the 2011 to 2016 emissions trajectory from national statistics,
- Quantifying the implemented mitigation initiatives to construct a counterfactual emissions trajectory, and
- Comparing the trend against the commitments made by South Africa under the Paris Agreement, and other forecasts.

South Africa ratified the Paris Agreement in November 2016 and committed to reducing GHG emissions on a “peak, plateau and decline” trajectory (Department of Environmental Affairs Republic of South Africa, 2015). This trajectory includes a target of reducing its GHG emissions to between 398 and 614 $MtCO_2$ eq (incl. land use, land use change and forestry (LULUCF) emissions), over the period 2025 to 2030. However, this target is equivalent to a 20-82% increase on 1990 levels excl. LULUCF as it is a target against a business-as-usual scenario (Department of Environmental Affairs Republic of South Africa, 2013a).

A combination of historical national GHG inventories and forecasts is used as a basis for national commitments to set reduction targets. The national GHG inventories are prepared in accordance with guidelines from the United Nations Framework Convention on Climate Change (UNFCCC). These guidelines are set by the Intergovernmental Panel on Climate Change (IPCC) to facilitate the calculation and reporting of national estimates of emissions and removals of GHGs. GHG inventories are prepared annually for developed countries, and on a two-year cycle for developing countries.

In South Africa, the latest publicly available inventory is for 2010 (Department of Environmental Affairs Republic of South Africa, 2014). This inventory was developed in accordance with the 2006 IPCC Guidelines. The UNFCCC published Good Practice Guidance reports. These reports provide a format for the definition of source categories and the calculation, documentation, and reporting of emissions. The guidelines contained in the reports aim to facilitate the calculation and reporting of inventories that are transparent, consistent, comparable, complete, and accurate. However, uncertainty in the underlying data can cause under or over-reporting of these inventories.

Before the Paris Agreement, the high uncertainty associated with national inventories was addressed by the IPCC providing additional guidelines, training, and calculation tools. However, with the Paris Agreement, the respective national inventories became the basis for the design of mitigation policies and measures, as well as the departure point to track progress.

4.2. Uncertainty in national GHG inventories

The national GHG inventories are the basis for evaluating the national reduction commitments of developed countries in terms of the requirements of the Kyoto Protocol, and for all countries who ratified the Paris Agreement. The Intergovernmental Panel on Climate Change (IPCC, 1996) has defined a complete method to standardise the GHG inventory on a national level. This method provides for the calculation of emission inventories within the geographical boundaries of a country. In the guidelines and good practice guides set by the IPCC, GHG emissions data is estimated, as opposed to measured. The estimation is necessary, as emissions from very few sources can be measured directly and continuously, whereas this is not practical for many sources spread over large geographical areas.

The emissions estimate from each source is based on activity data and emission factors. Most developing countries use default emission factors provided by the IPCC. This is to ensure a consistent, transparent, and comparable calculation over time. Although it is good practice and recommended to use precise national data when available, this is often not possible, as there may be high costs associated with the collection and processing of this data. The IPCC default factors use data obtained from several nations at different levels of economic development and represent a global average. Unfortunately, such emission inventories may have a high degree of uncertainty due to process variability in space and time, and there is limited transparency of the calculation. In their research on five developed countries, Rypdal and Winiwarter (2001) calculated that the uncertainty of GHG inventories ranges between 5% and 20%. More recent research on the sources of uncertainty for the Paris agreement concluded that the historic emission inventory on which developing countries base their reduction commitments has an imprecision of 10%. Overall historic emission inventory uncertainty towards the Paris Agreement was limited to 4% (Rogelj et al., 2017).

4.3. Analysis of mitigation actions implemented in South Africa

Only information in the public domain and reported in either the National Communications or the Biennial update report (Department of Environmental Affairs Republic of South Africa, 2017), or national statistics, are included in this study. The mitigation initiatives include the suite of Clean Development Mechanism projects (www.unfccc.org), the projects in the Demand Side Management programme of the national electricity utility (Eskom, 2016a), public energy efficiency projects, and large private sector fuel switch projects.

Emission reduction initiatives, programmes and projects that are still in the implementation phase or where actual reductions have not materialised yet are excluded to avoid over-estimation of emission reductions. These projected emission reductions can, however, form part of decarbonisation trajectories towards meeting the commitments and targets in the future. The date of including emissions from projects that are implemented in a phased approach can be complicated where limited verification reports or completion status is available in the public domain. Partly implemented projects should only be included if actual emission reductions can be confirmed.

Large-scale emission reduction initiatives in the electricity or waste sector can be quantified from published data, combined with regional appropriate characterisation factors. Quantification of emission reductions in the transport sector, where activity data is either not measured or publicly available, or collected by dispersed entities and not available in the public domain, is more complex and uncertain. Examples would be the modal shifts from road or rail, such as the petroleum pipeline (linking the coast and the interior, covering a distance of over 600 km), or the implementation of mass public transport systems in the metropolitan areas. The increased role of non-state actors, such as industry and cities, will also require an increased focus on monitoring and evaluation to reflect the actual impact of implemented mitigation action. In the pre-2016 period these initiatives were still obtaining funding, planning the implementation, or commenced pilot projects, but no large-scale emission reductions had materialised yet.

4.4. National greenhouse gas emissions of South Africa

The collation of data and the preparation of the South African national GHG inventory is the responsibility of the Department of Environmental Affairs. Approval of the GHG inventory is done through parliament. Both new inventories or recalculation of previous GHG inventories over previous time series are approved before submitting under international agreements.

4.4.1. The greenhouse gas inventory for the period 2000-2012.

In November 2014 South Africa submitted the 2010 national GHG inventory, together with an updated trend series from 2000 to 2010 to the UNFCCC. The methodology to compile the 2010 inventory and the restatement of the 2000 inventory was in accordance with the 2006 IPCC guidelines. With and without the restatement coal combustion remained the biggest emission source to the emissions inventory of South Africa.

In submitting the 2012 national GHG inventory, South Africa updated the 2000-2012 inventory for methodological consistency against the latest IPCC guidelines. The guidelines require that emissions in the energy sector be calculated by multiplying the amount of fuel used in the sector with the emission factor of the fuel. The electricity sector in South Africa uses sub-bituminous coal. The 2000-2010 national GHG inventory of South Africa uses a default calorific value for sub-bituminous coal of 24.3 GJ/t. The electricity utility – Eskom - publishes the actual average annual coal consumption, and coal calorific values, which over this period varied from the lowest in 2008 of 18.58 GJ/t, to the highest average annual value of 19.54 GJ/t in 2002 (Eskom, 2002), (Eskom,2008). This is consistently in the order of 20% less than the default calorific value for Tier 1 reporting in the latest IPCC guidelines. As primary energy generation is the largest contributor to the GHG inventory, and coal combustion the main emission source, the impact of this correction is significant.

The values presented in Figure 4-1 are calculated as follows:

- Eskom emissions from Eskom CV calculations: The tonnage of coal burnt by Eskom is multiplied by the actual CV values reported by Eskom, and the default emission factor for sub-bituminous coal,
- National inventory with GHG emissions from the electricity sector as per the national inventory: This is the value reported in the national inventory, and the CV used in these calculations is 24.3 GJ/ton, and
- National Inventory, if corrected for CV to match Eskom reported CVs: The reported emissions from the national inventory are corrected for the error in the CV values by using the actual CV values reported by Eskom.

The values for 2005 are adjusted, as Eskom reported 15 months' worth of operating data for the period from 1 January 2004 to 31 March 2005 due to a change in the financial year from a calendar-year to twelve months starting in April. The values from the Eskom annual report are, therefore, adjusted by the factor 12/15.

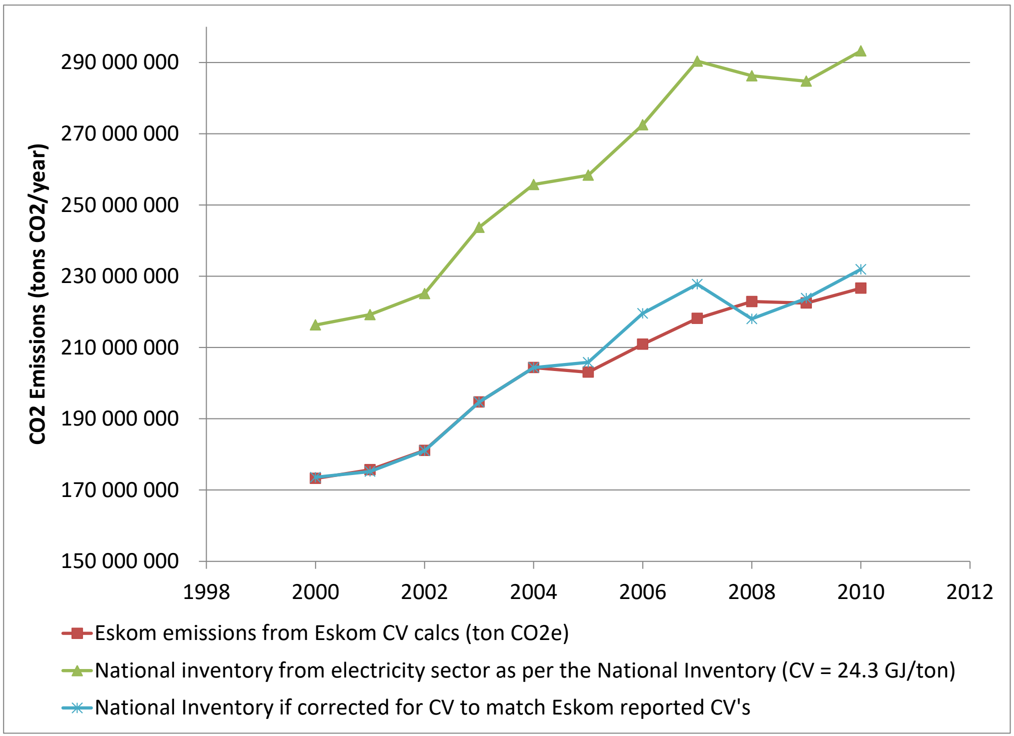

Figure 4-1 The influence of using actual coal calorific values, instead of default values on the national GHG inventory

4.4.2. A greenhouse gas inventory for the 2013-2017 period

Bridging the period since the latest published GHG inventory for the sectors other than the electricity sector relies on national statistics as a proxy. Adjustments are made using the composition of the 2012 national GHG inventory as an index. This calculation is based on the assumption that the structure of the economy and the relative contributions of the key sectors remained the same.

The carbon intensity of the economy in terms of the electricity demand against the GDP exhibits a significant downward trend since 2000. The overall carbon intensity of South Africa has been declining steadily since 2000, as is shown in the decoupling of the electricity intensity of the GDP in Figure 4-2. This is partly linked to increased energy efficiency due to the electricity availability declining, but also the significant increase in the cost of electricity over the same period. The low commodity price resulted in a decrease in output from the intensive energy industries, such as mining, or primary producers, such as iron, steel, ferro-alloy and cement producers. This is supported by the findings of Blignaut, Inglesi-Lotz, & Weideman (2015).

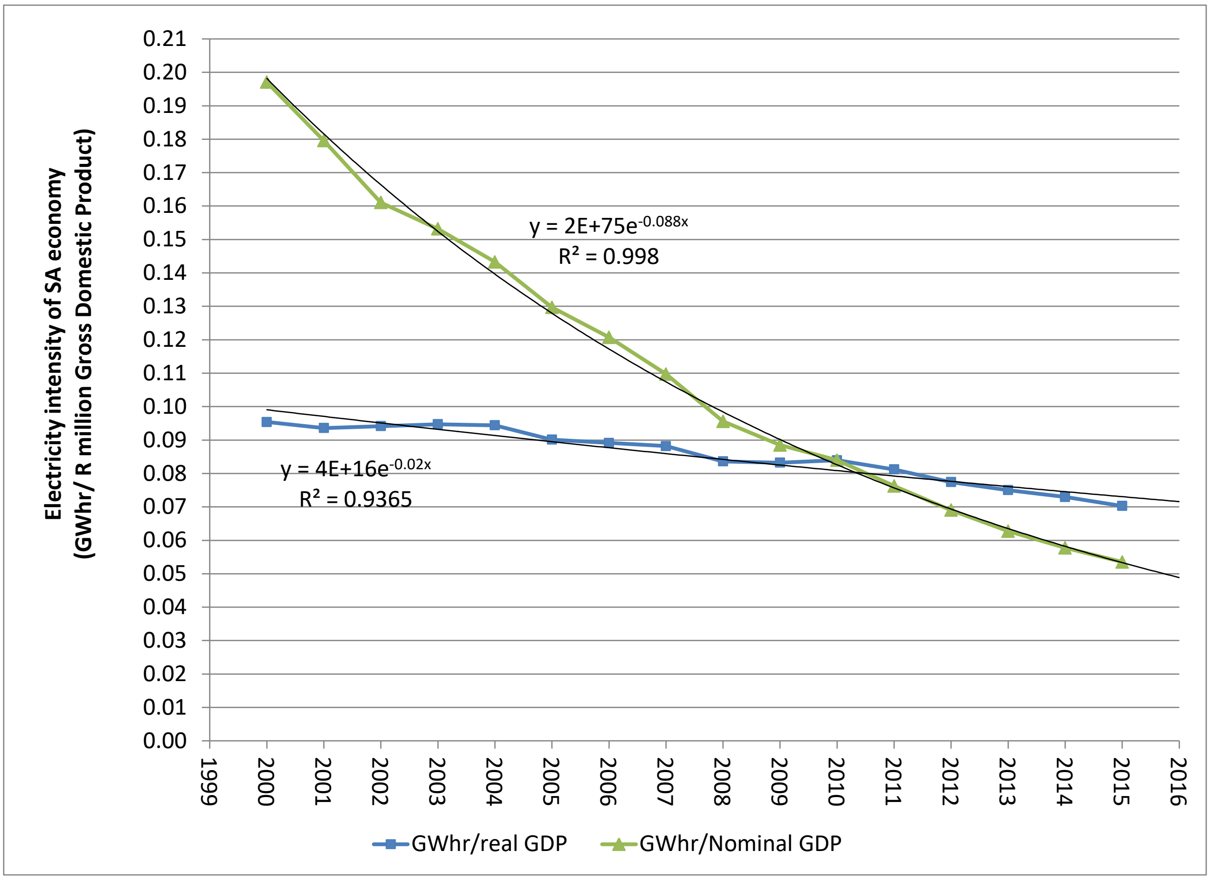

Figure 4-2 Decoupling of growth from electricity consumption since 2000

The estimated national emissions trajectory for the period from 2010 to 2016 is presented in the figure below. Adjustments from the 2012 national inventory with national statistics data show a clear downward trend for the last five years, 2012 to 2016.

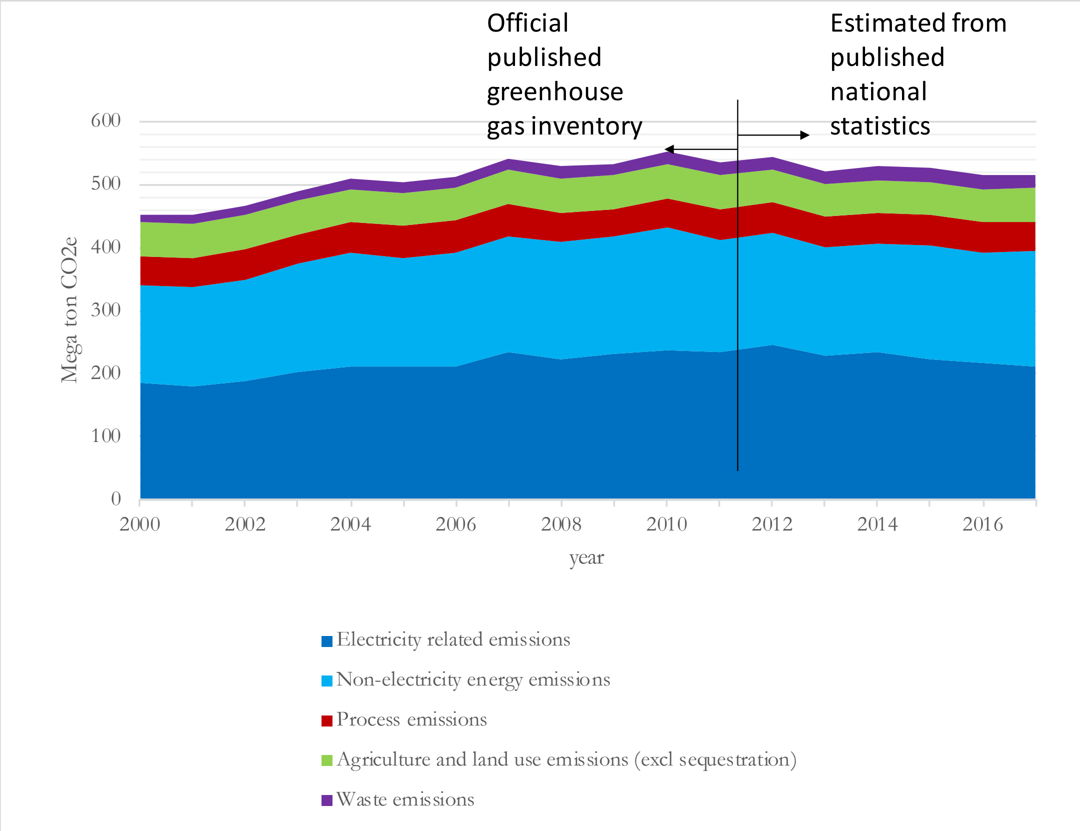

Figure 4-3 Bridging the data gap in the national inventory

The mitigation initiatives were added to the total restated value of the GHG inventory, as per figure 4-3. These mitigation initiatives are quantified and verified through national processes. Not all initiatives are cumulative and, therefore, annual calculations of the impact of the mitigation actions were required.

A range of national and industry programmes and projects were implemented since 2000, with the bulk of these being energy efficiency programmes and fuel switch projects. These projects are assumed to be non-reversible, and provide cumulative benefits of mitigation action over time. In the calender year 2017, about 267 $MtCO_2$ eq have been reduced (see Figure 4.4). If these projects were not implemented over the last 17 years, the national inventory would have approached 800 $MtCO_2$ eq in 2017. The end of new CDM project registrations in 2010 and the end of the industrial demand side management programme in 2014 had a negative impact on mitigation volumes, which were not replaced with other, similar-sized mitigation actions. However, the country still benefits from the cumulative impact of the projects that were implemented.

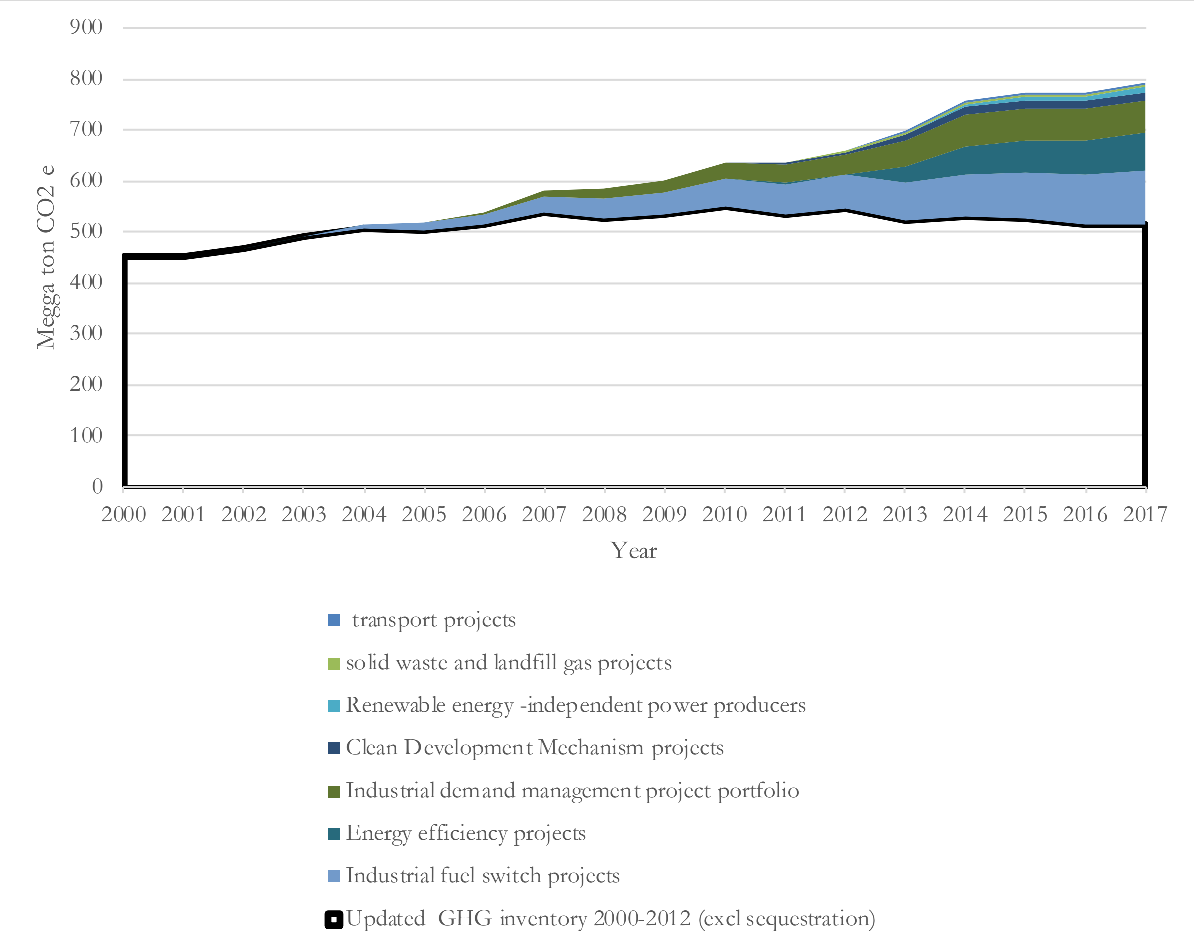

Figure 4-4 The impact of mitigation initiatives on the national inventory to show the counter factual baseline

The counterfactual baseline that consists of the inventory and the mitigation initiatives, indicates the progress towards the national GHG target, the National Determined Contribution. The progress towards the range that South Africa presented as the National Determined Contribution is shown in Figure 4-5. Comparing the national emissions trajectory to the commitments made in the Paris Agreement shows that the GHG emissions have already been reduced to within National Determined Contribution of the “Peak, Plateau and decline” range (see Figure 4-5). Between 2000 and 2010, South Africa’s GHG emissions (with a default Calorific Value of 24.3 GJ/t for sub-bituminous coal used in developing countries) were within the national goal of the “Peak, Plateau and Decline” trajectory. Even with the revised Calorific Value for the actual calorific value of the coal consumed, the downward trajectory of the national GHG emissions remain above the lower limit.

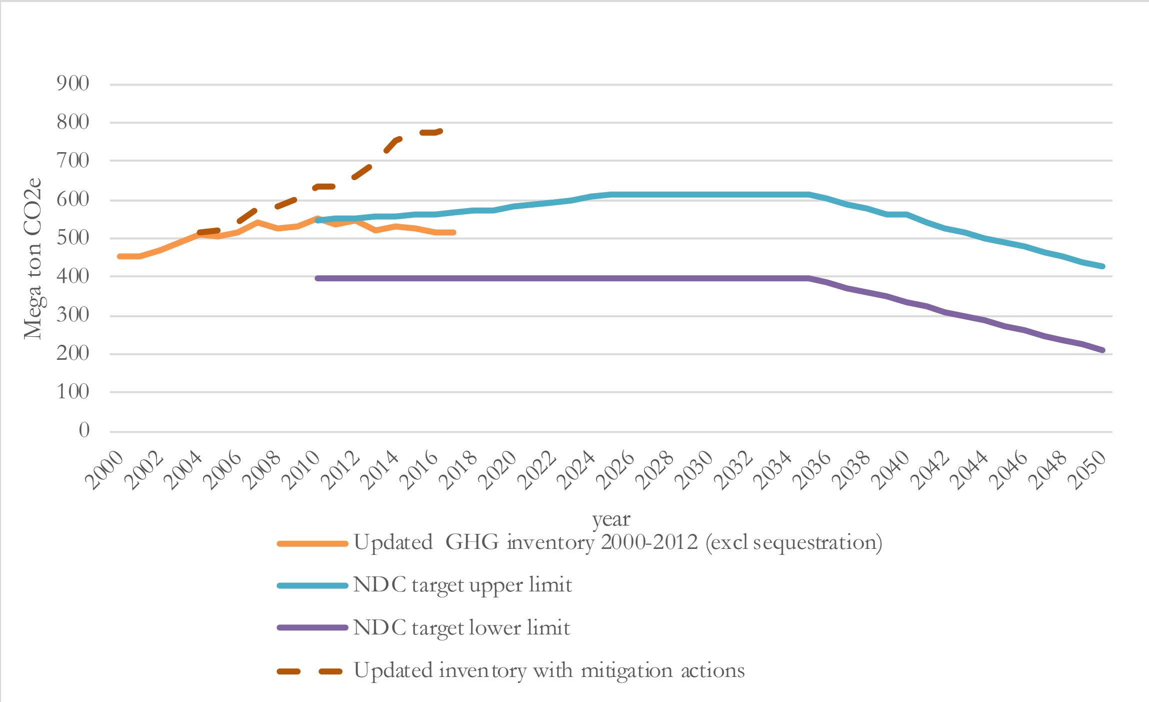

Figure 4-5 The forecasted national commitment, the National Determined Contributions, against the estimated GHG inventory and the counterfactual baseline

The counterfactual baseline, the sum of the inventory and the implemented mitigation actions for 2017 is 792 $MtCO_2$ eq. In 2010 and every subsequent year, South Africa's net emissions of 518 $MtCO_2$ eq were within the PPD trajectory target of 398 $MtCO_2$ eq (lower limit) and 547 $MtCO_2$ eq (upper limit) for that year. The implied "carbon budget" between the country's 2010 emissions level of 518 $MtCO_2$ eq, and the maximum emissions level of 614 $MtCO_2$ eq presented in the country's Nationally Determined Contributions for 2025, is about 96 $MtCO_2$ eq according to the DEA report (Department of Environmental Affairs Republic of South Africa, 2017). However, from this research, it could be much higher. For the 2011 to 2017 period, the calculated GHG emissions peaked in 2012 and decreased after that, but still remain above the lower limit.

Tracking the direction of the trend is increasingly important, as the cost of implementing mitigation measures and plans could assist in planning appropriate policies and support measures.

Decreasing the electricity intensity as proposed by Inglesi-Lotz & Blignaut (2014), will indeed also contribute to a decoupling of growth from GHG emissions. However, as a stand-alone mitigation initiative, it will be costly while less costly mitigation alternatives are available in other emission sources and emission categories.

4.5. Conclusion on the applicability of the analytical technique for a country

In this case study, the use of national statistics was evaluated to complement or develop recent national GHG inventories, and support action-based targets.

From annual trade statistics, the post-2010 national emission trajectory was estimated and compared to the ’peak, plateau and decline’ trajectory that form part of South Africa’s international GHG commitment. The combination of quantified mitigation actions on the total emission trajectory can overcome some of the uncertainty of the national GHG emissions inventory, which is strongly influenced by external macro economic factors. This combination results in a useful climate action infographic. One climate action infographic visually presenting the progress against the commitments could assist in raising awareness about the importance of updating the GHG inventory and provide understanding for wide range of stakeholders. This new analytical technique was applicable for assessing the South African national GHG inventory and allows utilisation of other available national data to track the decarbonisation of the country.

5. Application of the model on mining companies

5.1. Introduction

The decarbonisation of the mining sector in South Africa is closely linked to the energy consumption patterns and energy targets of the mining companies.

The objective of this case study is to examine the indicators for forecasting GHG emissions in the mining sector of South Africa and to evaluate progress against publicly announced GHG targets. The metrics and publicly available data used in managing GHG inventories, for both an underground mining company and an opencast mining company, are analysed. Both companies signed the South African Energy Efficiency Accord in 2005. Under this Accord, both companies committed to a reduction target of 15% below the baseline by 2015, while the government committed to creating an enabling environment for energy efficiency improvements. The target contained in the energy efficiency accord, and signed by the companies, was not clear. Depending on which intensity metric is used the absolute reduction would change. The normal execution of standard functional operations within an organisation, particularly in contrast to a project or program which would introduce change (although that change may itself become business as usual).

In 2005, the South African Department of Minerals and Energy launched a national energy efficiency strategy for overall energy efficiency improvement of 12% by 2015. This 12% energy efficiency target was disaggregated per sector of the economy, recognising that residential and commercial sectors have less energy efficiency improvement potential than energy-intensive sectors. Through the National Business Initiative[11] (NBI), an energy efficiency accord was signed in the same year between the DME and 24 energy-intensive companies (Department of Minerals and Energy, 2005). Against this accord, the signatories acknowledged the national target, regarding the energy efficiency strategy of South Africa and a target for the industry and mining sector of 15% energy reduction by 2015, against a 2000 baseline year. However, signatories had limited data going back to 2000, and even where energy data exists from 2000, the improvement of data quality since then with respect to completeness and accuracy, means the early data sets are not useful for any analysis or comparative studies. For these reasons, the date of signing the accord was substituted as the baseline year, 2005.

[11] www.nbi.org.za

In 2005/2006, mining activities directly contributed 6.2% to the South African Gross Domestic Product (GDP) while consuming 31 825 Gigawatt hours (GWh) of electricity annually (Chamber of Mines, 2006). In 2015, the direct contribution to GDP increased to 7.7%, with annual energy consumption decreasing to 30 720 GWh (Chamber of Mines, 2016). The mining sector still provides more than half a million direct job opportunities, making it a vital part of the South African economy. Decarbonisation policies should, therefore, be designed with care so as to protect the competitiveness of the country's mining industry, through the envisaged transition to a lower carbon and climate resilient economy (Harald Winkler, Jooste & Marquard, 2010).

Mining is highly energy intensive, both in the initial development stage and throughout the life of a mine. Within opencast mining operations, liquid fuel, mainly diesel, is the primary energy carrier. In South Africa's underground mines, grid electricity is the primary energy carrier, not only for production and ore transport, but also for critical safety applications, such as ventilation, cooling, water pumping, and personnel hoisting. The main energy requirements of the fixed mining infrastructure are interlinked, but have been well documented and can be categorised in one of the following four areas:

- Integrated water reticulation, which would include dewatering systems and underground water supply. This can account for as much as 42% of the total energy consumption on a deep level gold mine (Vosloo et al., 2012),

- Cooling systems are integrated with the water reticulation system to provide chilled service water to the mine, as well as cooling of the mine ventilation air. This can consume up to 25% of the total electricity used in deep-level mines (du Plessis et al., 2013). The underground air temperature is site-specific and increases with depth. The quality of mine ventilation air, in terms of temperature, humidity, and airborne dust limits, is well regulated and mandatory annual reports are required, as prescribed in the South African Mines Occupational Hygiene Code (Department of Mineral Resources, 2002) and under section 12 of the Mine Health and Safety Act, 29 of 1996 (Department of Mineral Resources, 1996),

- Electrical mine ventilation fans operate continuously to meet the minimum air quality standards and to clear the air after blasting. An estimated 14% of the electricity used can be directly attributed to mine ventilation fans (Panigrahi & Mishra, 2014);

- Compressed air systems function both as an energy carrier for drilling and emergency-bay air ventilation. Typically, older mining operations have several compressors at each mining shaft with each compressor operating on a stop/start basis. These compressors could be either diesel or electric installations. The control is managed by pressure switches, which activate on a minimum pressure and deactivate on a maximum pressure. As the mining operation expands, air lines increase in length and age. Consequently, air leaks are considered the single largest source of energy wastage in South African hard rock mining operations (Johnson & Fourie, 2012). The more recent designs of mining infrastructure connect different shafts to one compressed air ring, which is supported by a number of compressors.

The cost of energy carriers, together with labour costs, forms the largest operational expenditure of active operational mines. The government regulates the price and quality of liquid fuels in South Africa. Electricity tariffs are set by the National Energy Regulator of South Africa (NERSA), while most of the generation and distribution of electricity on the grid is the sole responsibility of one government-owned utility, Eskom. The official statistics report on the Mining industry in 2009 and 2012, lists liquid fuels and electricity at 40% of the total expenses of mining companies in South Africa (Lehohla, 2012). Eskom’s average increases for electricity tariffs over the past 19 years were below inflation until 2003, but have risen to above inflation levels since 2003 (Pietersen, 2007). The cost of energy has increased rapidly over the last five years, thus reducing the margins of operational facilities.

The electricity price increases are published by Eskom as average prices per sector (Eskom 2016). The electricity price increases for the mining sector were substantial, with an average increase over the decade of 15.1% per year, and two consecutive years with increases above 30%. See Figure 5-1 for the annual electricity price trajectory for the mining sector.

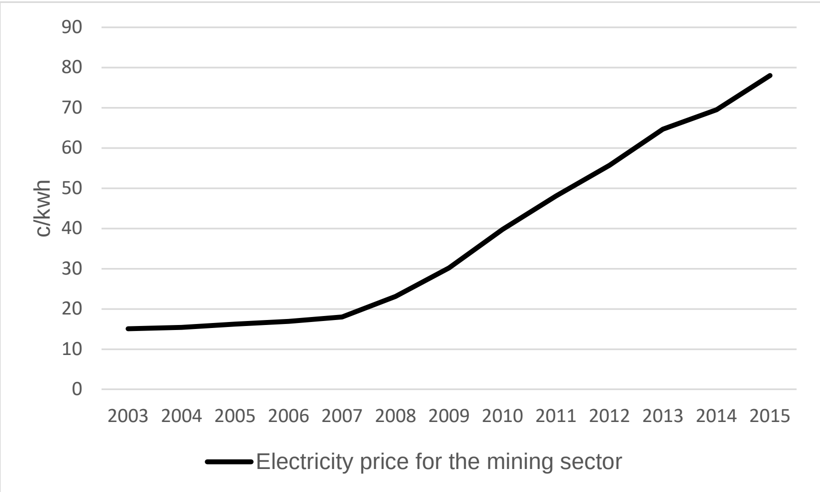

Figure 5-1 Eskom average electricity price for the mining sector

(Source: Eskom historical prices and increases report 2016)

The wholesale diesel price also increased substantially over the same period. The Department of Energy publishes the Basic Price of Diesel, without taxes and levies. The wholesale price is published in the annual reports of the South Africa Petroleum Industry Association (SAPIA, 2015). The average price of diesel increased by 14% per year over the ten-year period (see Figure 5-2).

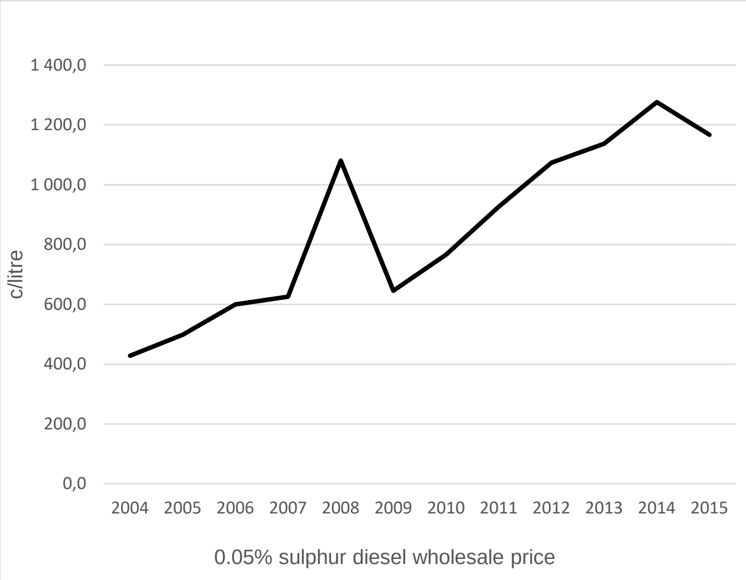

Figure 5-2 Diesel price increases from 2004 to 2015

(Source: SAPIA annual report 2015)

The GHG emissions associated with the use of these two energy carriers are accounted for differently. The combustion of liquid fuel is counted as direct emissions from the mining facility. The GHG emissions of grid electricity occur at the generation facilities, outside the organisational boundaries of the mining facility and, therefore, are accounted for as indirect emissions.

Mining investments are long-term investments. Mines that were designed twenty years ago, seldom have optimal operations or efficient infrastructure today. However, the mining industry has actively reduced its energy consumption significantly since 2010 in response to the rising cost of energy. The energy consumption of a mine is linked to the fixed energy-consuming infrastructure that forms part of the mine design. Most mines require large absolute volumes of energy and are, therefore, a significant source of GHG emissions. However, there are also significant GHG emissions saving opportunities available to companies in this sector. These opportunities would be either through reducing energy demand or through the implementation of energy efficiency initiatives. The long-term planning of mining operations is contained in a life of mine plan. In accordance with the South African code for the reporting of exploration results, mineral resources, and mineral reserves, the life of mine plan is a design and costing study of an existing operation, in which appropriate assessments have been made (SAMREC, 2007). These assessments must include assumptions on geological, mining, metallurgical, economic, marketing, legal, environmental, social, governmental, engineering, operational and all other modifying factors, which must be considered in sufficient detail to demonstrate, at the time of reporting, that extraction is reasonably justified. Based on the long-term energy requirement during the life of mine, forecasting of the GHG emissions profile over the same period can be carried out. However, the life of mine plan and subsequently the long-term energy plan is usually not made publicly available.

5.2. GHG emissions in a gold mining company

Gold Fields Limited[12] is an unhedged, globally diversified producer of gold with eight operating mines in Australia, Ghana, Peru and South Africa. In February 2013, Gold Fields unbundled its mature, underground Kloof-Driefontein Complex and Beatrix mines in South Africa, into an independent and separately listed company, Sibanye Gold[13].

In 2012, Gold Fields celebrated 125 years as a global gold producer, with the annual gold production of approximately 2.02 million ounces, mineral reserves of around 49 million ounces, and mineral resources of about 113 million ounces. In 2016, Gold Fields still ranked seventh in the world in terms of gold production, while Sibanye Gold ranked tenth. Gold Fields has been in the top five of the South African Carbon Disclosure Leadership Index since the start of the CDP initiative and Gold Fields had signed the Energy Efficiency Accord in 2005. Therefore, both the data to evaluate the GHG emissions and the target has been made publicly available.

The relevant output metric for Gold Fields is either tonne milled or gold produced. These two metrics are both used to report the operational performance of the company and were, therefore, used to analyse the historical GHG emissions for forecasting and performance against the set target. For this paper, only the emissions associated with the South African operations were used, as the 15% target of the Energy Efficiency Accord was a South African initiative.

[12] www.goldfields.co.za

[13] www.sibanyegold.co.za

5.3. Greenhouse gas inventory data of a gold mining company

In the 2005 base year, Gold Fields milled 15 530 000 tonnes of ore and reported direct and energy indirect GHG emissions of 4 952 930 tCO_2 eq, while producing 2 824 000 ounces of gold. A production forecast was constructed on the statement in the 2005 Annual Report "Our growth strategy remains to achieve a 50:50 split between South African and international production by 2009, thereby building a bigger footprint and balancing our portfolio to reduce technical, product and geographical risk. Our growth strategy of adding 1.5 million ounces of offshore production to our portfolio by 2009 remains unchanged, and we continue to focus on building a strong internationally diversified portfolio of high quality, long life assets."(Gold Fields, 2005 page 13). The portfolio of the South African operations in Gold Fields remained the same during this period. A stable production rate for the South African Gold Fields operations was assumed to extent up to the target period of 2015. The ore grades are variable, but declining in the South African operations. As ore grades impact directly on the energy intensity of the operations, an average of 5% per year as a fixed decline is used internally in Gold Fields for planning and design purposes. Such a fixed decline against a stable output would require an increase in tonnes milled of 5% per year. Figure 5-3 shows the forecast growth trajectory that was envisioned in 2005. This growth trajectory is available for both metrics: a production output in ounces, and an operational metric in tonnes of ore milled.

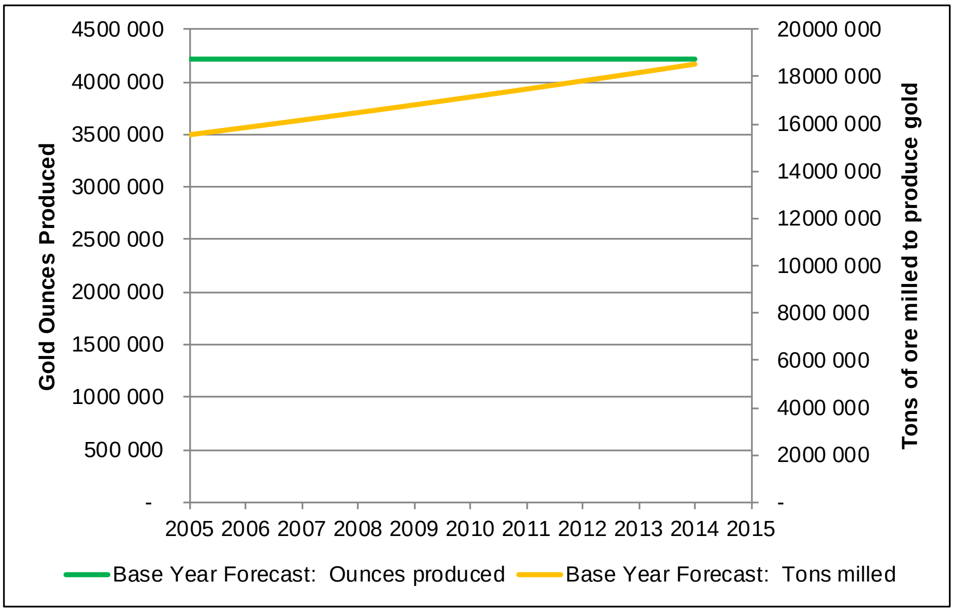

Figure 5-3 Production forecasts for Gold Fields' South African underground mines, based on 2005 information

Figure 5-3 shows the results of applying the chosen growth forecast to the 2005 production results, using both the ore mined and gold produced metrics. To maintain the ounces produced, more ore has to be milled and processed over the ten-year target period.

With the commitment of reducing 15% of the GHG emissions by 2015, the absolute value of the target depends on the chosen metric. The target of a 15% reduction over a ten-year period would require an average annual reduction of 1.6% per year as the annual growth or decrease will be compounding. This is shown in the figure below, using the planned growth rate with the emission intensity in 2005 as a basis to forecast the emission trajectory for each of the two metrics. With the ounce's gold produced metrics, the absolute target for reduction is equivalent to 6,321,800 tCO_2 eq over the ten-year period. With the tonnes milled metric, the absolute target for reduction is equivalent to 10,297,500 tCO_2 eq over the period.

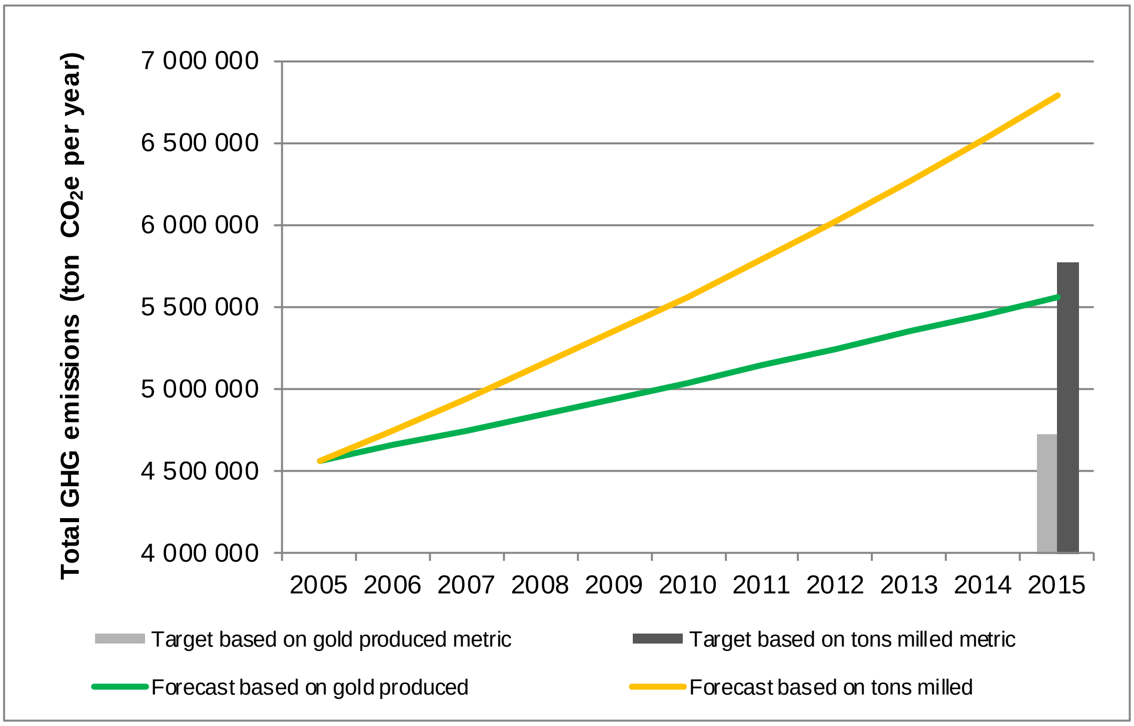

Figure 5-4 Greenhouse gas emissions forecasts and reduction targets for Gold Fields' South African underground mines, for both production metrics

Depending on the chosen metric the absolute target differed. However, both metrics would require mitigation actions of a similar scale at 1.5% per year over a decade to reach the target.

The GHG inventory is calculated annually from consumption records and published with a list of the implemented emission saving projects. As the Accord covered the decade from 2005 to 2015, the progress against the target was assessed using the Gold Fields data published between 2005 and 2016. The documented emission savings from projects implemented during this period were added to the actual emissions from the annual GHG inventory. Although records exist of the implemented emission reduction activities, the emphasis on the recording and reporting of savings was not a high priority during this period. GHG emission savings from smaller or dispersed projects were not reported, consolidated or verified.

The GHG inventory, as well as documented emission reductions associated with implemented projects, are independent of any production metric.

Due to a split of the Gold Fields assets in 2012, with only the South Deep mine remaining in the Gold Fields portfolio, the comparison of forecast emissions versus actual emissions had to be extended. As stated above, Gold Fields created a new South African gold mining company called Sibanye Gold, as part of the unbundling. Therefore, in 2012 the remainder of the South African operations were owned by Sibanye Gold, also a JSE listed entity. In accordance with the ISO 14064-1 standard on GHG accounting "an organisation shall develop, apply and document a base-year recalculation procedure to account for… the ownership and control of GHG sources or sinks transferred into or out of organisational boundaries" (International Organization for Standardization, 2006). Emission reductions initiatives were undertaken and publicly reported for both entities. Figure 5-5 shows the recalculated inventories, combined with the respective mitigation activities. After the portfolio split, the actual emission inventory of Gold Fields reduced by more than 90%, with most of the emissions and emission reduction activities under the ownership and control of Sibanye Gold.

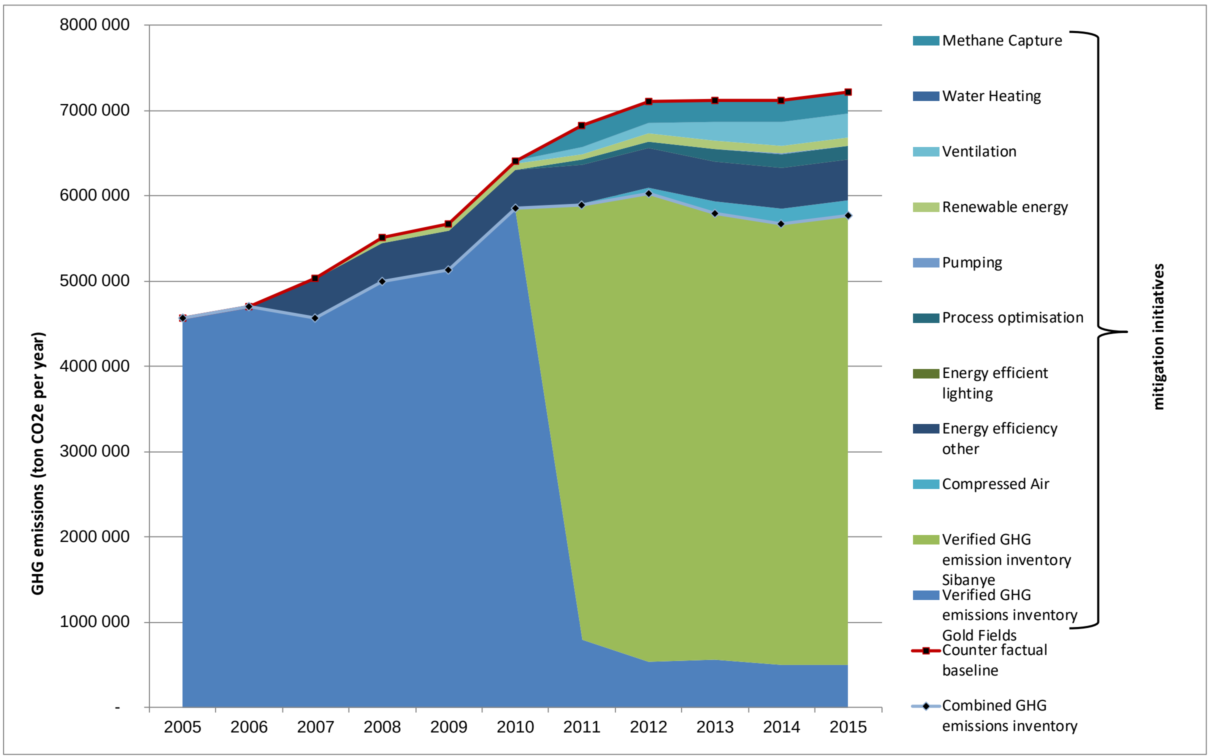

Figure 5-5 Actual and verified emissions and mitigation activities for the mining assets that belonged to Gold Fields in 2005

Not all emission reduction initiatives are permanent. The energy efficiency initiatives implemented in the Johannesburg Parktown head office have only been included for the period while Gold Fields occupied the building. The process and energy efficiency projects at the mines were deemed permanent and, therefore, accumulated emission reductions every year after implementation. The overall GHG emission savings of the original portfolio of mining assets, that formed part of the group in 2005, is estimated to be 15.3% below the business-as-usual baseline, based on the reported savings. The overall progress towards the emission target was thus achieved through mitigation projects that were implemented in the facilities that did not remain under Gold Fields' control over the period of the Energy Efficiency Accord.

The actual emissions of the combined set of mining assets are, however, lower than any of the forecast target values (see Figure 5.6).

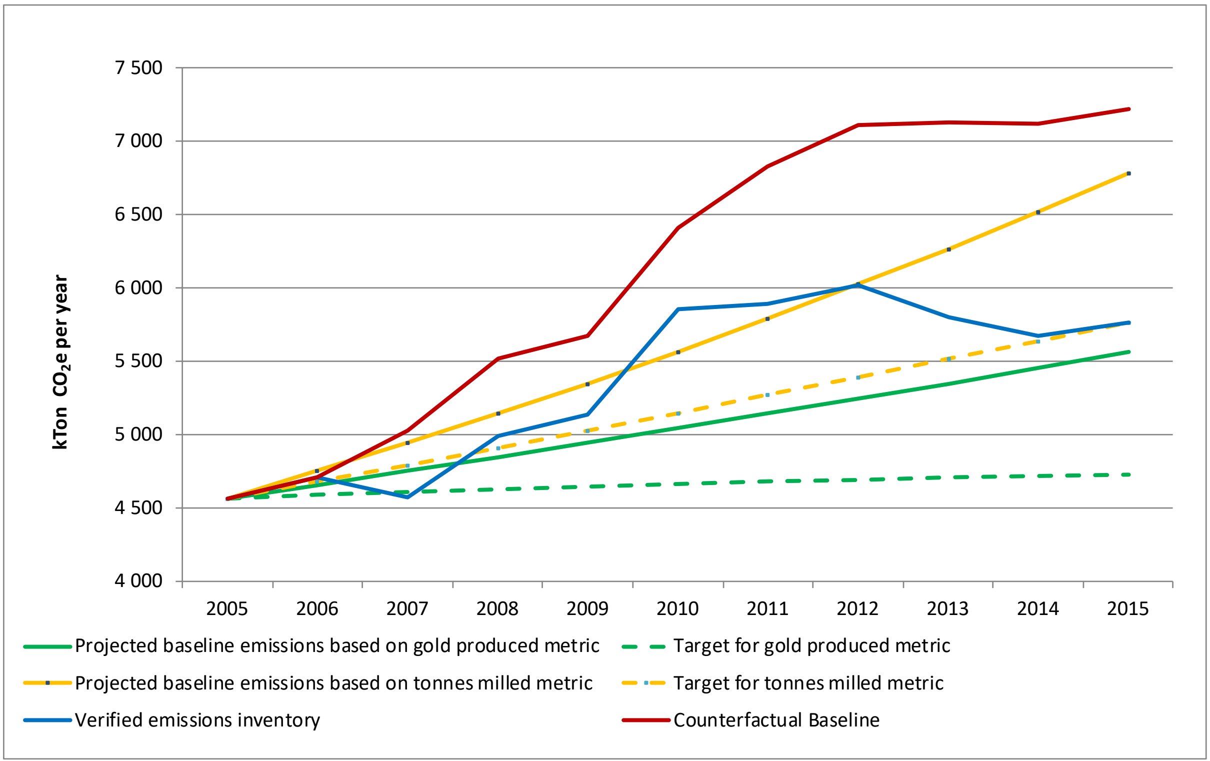

Figure 5-6 Combined analysis of forecasts and targets, against the actual baseline and GHG inventory of the assets that were owned by Gold Fields in 2005

5.4. GHG emissions in an iron ore mining company

Kumba Iron Ore Limited[14], a member of the Anglo American Plc. group is a value-adding supplier of high-quality iron ore to the global steel industry. It is the fifth largest supplier of seaborne iron ore in the world, exporting more than 37 million tonnes per annum to steelmakers in Europe, the Middle-East, and Asia. It also supplies 4 million tonnes to the South African market.

The company has three mining operations in South Africa, namely: Sishen Mine, Thabazimbi Mine, and Kolomela Mine. Both Sishen and Kolomela are long-life operations with the current life of mine estimates of 18 and 29 years respectively. Thabazimbi mine is nearing the end of its life, but Kumba has already undertaken a feasibility study on the Phoenix Project, adjacent to Thabazimbi, as a possible replacement.

Based on the ambiguous wording of the target in the Energy Efficiency it did not require an absolute reduction. Therefore the denominator in the intensity based calculation could be either tonnes ore mined or iron ore produced.

The high stripping ratio has impacted negatively on the energy consumption and associated GHG emissions for Kumba. The ore mined metric, when adjusted for actual production and the actual grid emission factor, provides a good estimation of the actual emissions inventory for Kumba. In contrast, the iron ore produced metric did not correlate well with the actual emissions, as the high stripping ratio is not reflected. The metric that was most suitable to use for forecasting Kumba's emissions profile is the metric based on tonnes ore mined, as it includes the impact of the high stripping ratio. The tonnes mined metric thus has the highest accuracy and would, therefore, be a better metric to use for future target setting and forecasting for these iron ore mining operations.

[14] *www.angloamericankumba.com*

5.5. Greenhouse gas inventory data of an iron ore mining company

In 2005 the Kumba Iron Ore Company (Kumba) published a growth strategy with an overall production forecast of 70 million tonnes per annum. This ten year forecast was linked to the implementation of specific projects and mining assets (Kumba, 2006). See Figure 5-7 for the planned production forecast per project.

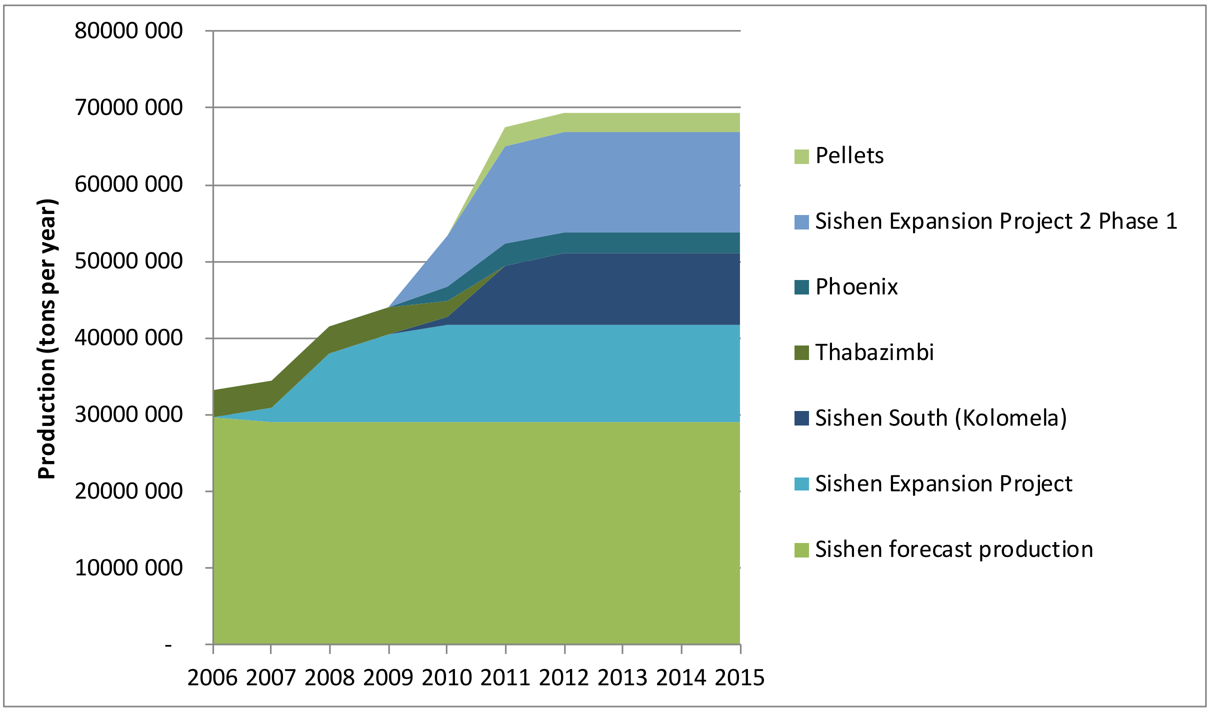

Figure 5-7 Kumba production forecast (source: Anglo American Kumba growth strategy, investors' presentation Dec 2016)

Kumba signed the Energy Efficiency Accord in 2006 and had been participating in the Carbon Disclosure Project since 2011. The verified GHG inventory, as well as information on implemented emission reduction projects, are publicly available.

At Kumba, the metric for output is defined as either an amount of iron ore product (tonnes produced) or the amount of material mined to deliver the product (tonnes mined). The GHG emissions are directly linked to the energy required to move the volume of rock, and this changes in the different phases of the life of a mine. In the development phase of a mine, large volumes of rock are moved with little production output. As the mine reaches the end of life, the lower ore grade and increased distance from the pit to the processing plant become more significant factors in energy consumption.

The GHG forecast for both metrics can be calculated based on the production forecast for the period 2006 to 2015, and the energy intensity of the mine in 2005 (Kumba, 2006),(Kumba, 2010),(Kumba Iron Ore, 2016). Figure 5-8 below shows the projected emission forecast from 20015 up to 2015, for the mines that are owned by the Kumba mining company. The target as per the Accord is a 15% reduction below business-as-usual by 2015.

The largest source of GHG emissions for Kumba is the combustion of liquid fuel, therefore, the forecast values assumed the grid emission factor would either remain the same or would not affect the overall results significantly. The composition of liquid fuel is regulated and the density as well as the associated GHG emission factors remained constant.

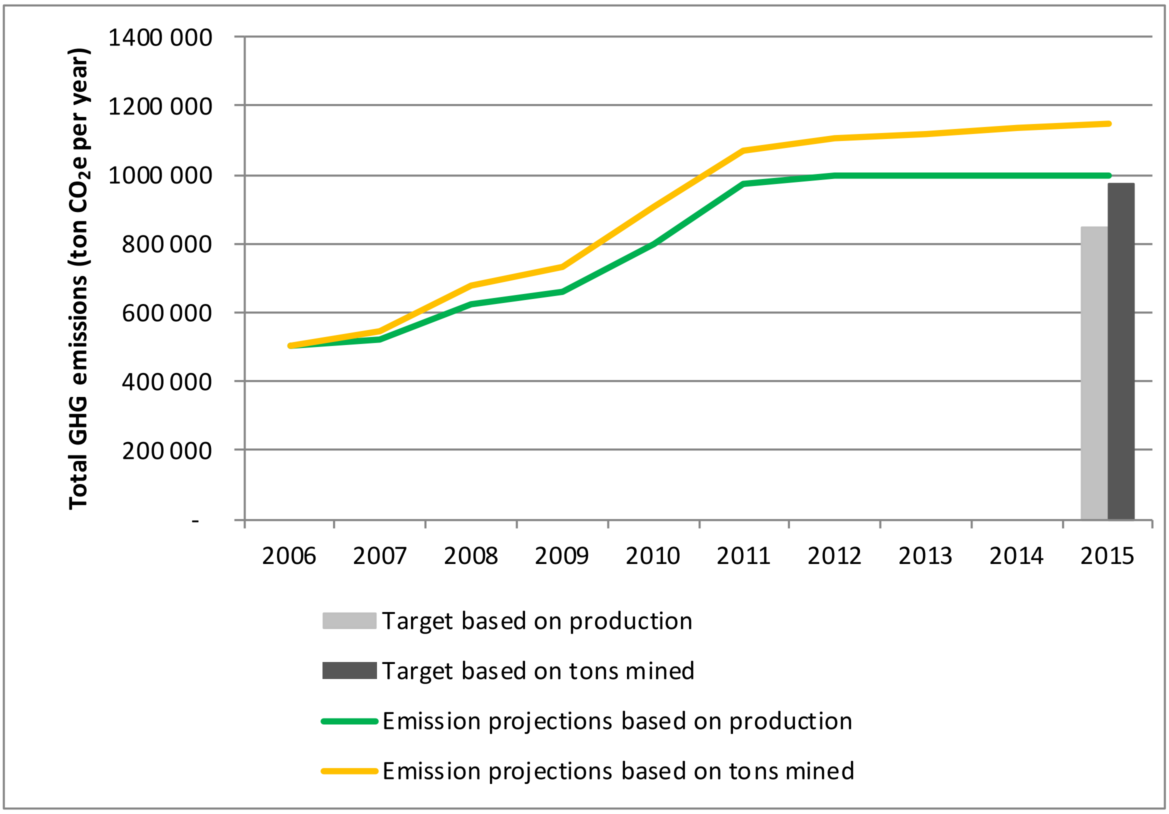

Figure 5-8 Greenhouse gas emissions forecasts for Kumba Iron Ore opencast mines, using both production metrics

A number of emission reduction projects were implemented over the period. However, while not all the growth projects were implemented, due to a severe decline in the international market for commodities in general, specifically iron ore. This decline constrained the capital available to develop and grow the Kumba operations.

For the emission reduction projects that were verified and reported publicly, it is assumed that the emission reduction benefits are permanent. This assumption is valid for technology-based energy efficiency projects and process optimisation initiatives where business as usual alternative has been removed. Diesel saving projects linked to behaviour changes are reversible, as the drivers change and attention is diverted from the diesel reduction initiative. Kumba has, however, implemented an automated diesel energy efficiency management system and the continued savings is managed on a monthly basis. These values were, therefore, cumulatively added to calculate the impact of the overall emission reduction projects implemented between 2006 and 2015. The actual inventory, the area at the bottom of the graph (in Figure 5-9), is the actual calculated and reported annual GHG emissions, independent of any emission reduction initiatives. No new mines were acquired, and no mine was sold during the 2006 and 2015 period. Due to the global reduced demand for iron ore the expansion and growth projects were put on hold.

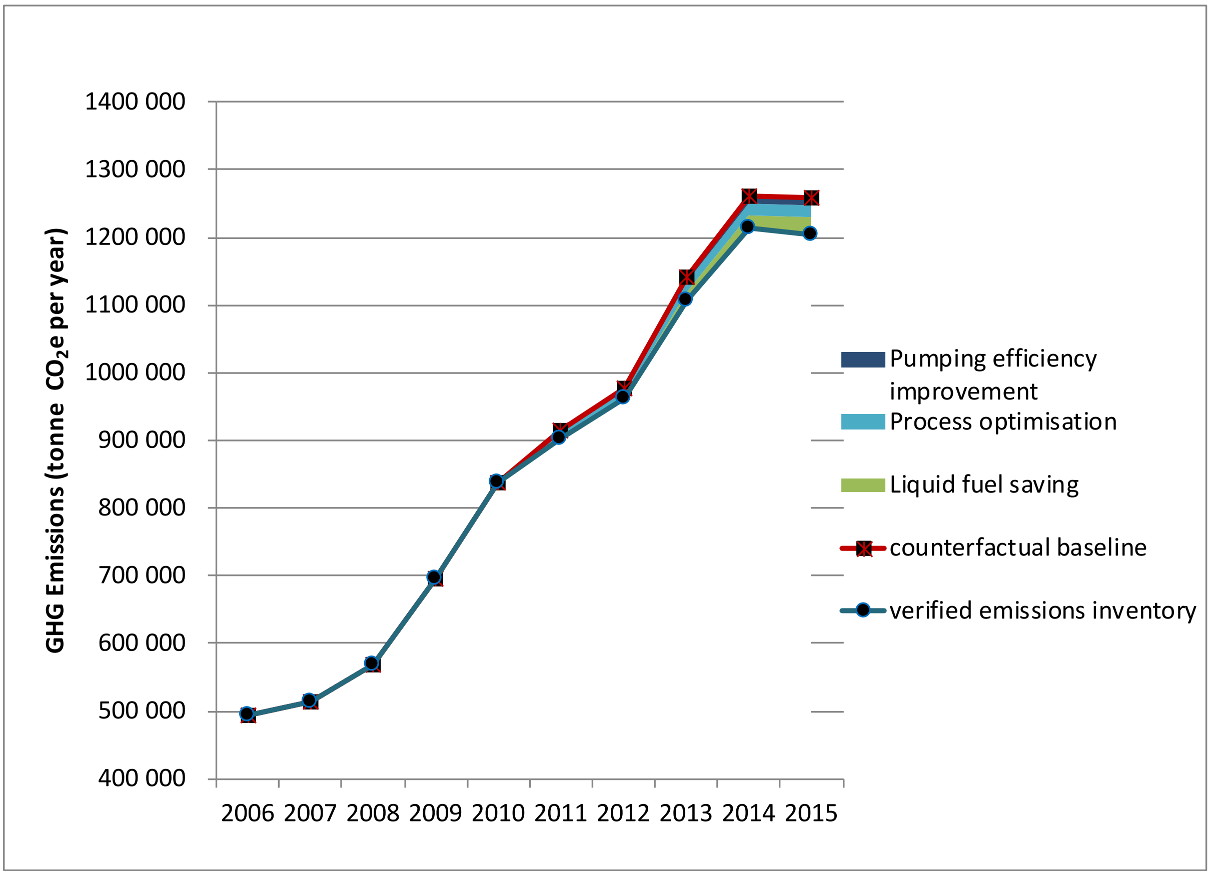

Figure 5-9 Actual and verified emissions and mitigation activities for the Kumba group

Although the mining portfolio stayed the same and the iron ore production remained stable, the tonnes of ore mined increased significantly. The iron ore production was below the projected value, while the tonnes mined increased significantly. In mining operations, the stripping ratio or strip ratio, refers to the ratio of the volume of overburden (or waste material) required to be handled in order to extract some volume of ore. For example, a 3:1 stripping ratio means that mining one cubic meter of ore will require mining three cubic meters of waste rock (Darling, 2011). The Kumba stripping ratio varied between the three different mines, with an average over the decade of 5:1. The Sishen mine exceeded a 20:1 ratio for four years in a row. Therefore, the overall emissions inventory (the solid blue line in Fig 5-10) are higher than forecast, as the forecast included the development of the expansion projects. The expansion projects were put on hold and the emissions inventory does not show any significant decline.

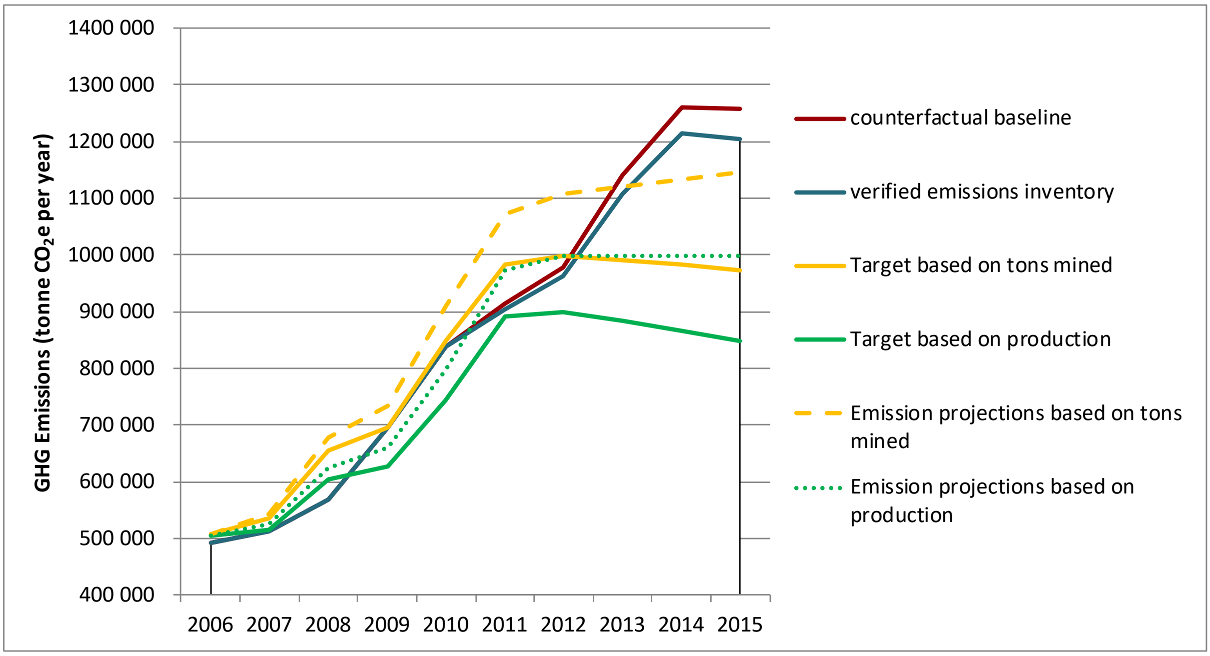

Figure 5-10 Combined assessment of actual versus forecast values for Kumba Iron Ore

The overall savings of the original portfolio of mining assets is estimated to be 8% below the counterfactual baseline, based on the reported savings from all three Kumba mines as in Figure 5-10 .

5.6. Discussion

The extended labour unrests and strikes in the South African mining sector in 2013 had little impact on the sector's GHG emissions trajectory. Although the production volumes were affected, the fixed underground infrastructure is a design feature for underground mines and requires energy independent of operational stoppages. Opencast facilities can, to some extent, scale down the dewatering of the pit and reduce the onsite material transport during such operational stoppages.

For both Kumba and Gold Fields, the metric that is best suited for approximating the actual GHG emissions is the operational metric of tonnes of ore milled or tonnes of ore mined. The production metric, which is easier to track from the annual reports for these mining companies, was not a useful metric for forecasting and would not be an appropriate metrics on which to base target setting.

Using reported production metrics for GHG target setting, as is current practice, hampers the decarbonisation transition. GHG emissions are not directly related to the production values, and it would be difficult to guide short-term policy to be consistent with long-term sectoral or national GHG reduction goals.

Mining companies can adopt an approach whereby the counterfactual baseline is calculated, by adding the implemented GHG emission savings to the actual annual GHG inventory, as determined and verified on an annual basis. This approach will, however, if adopted require more accurate reporting of the implemented emission savings initiatives. The GHG inventory itself is influenced by factors such as the production profile, the grid emission factor, stripping ratio, and the change of demand for the commodity. Although the inventory itself does provide a useful indicator of actual GHG emissions trends over time, it does not reflect the mitigation actions taken. The actual mitigation activities indicate of the commitment towards decarbonisation, and the benefit thereof will remain in place when demand increases again in positive economic cycles.

This is in line with Korean findings on both historical baselines and performances against targets. Korean companies found that, where demand is not factored into the GHG emissions target, the entities could not meet the set goals (Y. Lee et al., 2013). On the climate action infograph the emission reductions linked to actual emission reduction activities are clearly portrayed instead of emission reductions from external factors, such as reduced demand.

5.7. Conclusion on the applicability of the analytical technique for a mining company

The ex-post methodology creates an actual GHG baseline, using two existing data sets, to derive the benchmark or distance from a target. The first set of data is the actual emissions of the facility or company. This information is available in the public domain for large, listed entities. The second set of data is implemented emission reduction activities and the actual emission reductions achieved over time to reduce either energy consumption or GHG emissions. The actual baseline is the sum of the GHG emissions and the achieved emission reductions. This would be the theoretical emission trajectory for a company if the emission reduction activities were not implemented.

Within the ex-post methodology, the inventory reflects the actual changes of demand and other external factors. Combining the inventory with the implemented emission reduction activities allows an assessment of how the overall emission reduction can be linked to the GHG mitigation actions. When forecasting or target setting, the focus should remain on the emission reduction potential and the contribution it could make in lowering the GHG emissions inventory.

In an evaluation of policy implementation in Western Europe, the need for not only improved accounting of GHG emissions and forecasts but also of mitigation options, has been highlighted as essential to support improved target setting and national mitigation strategies. Even though cyclical monitoring and reporting is in place and supported by national strategies, it has played a limited role in facilitating research (Casado-Asensio & Steurer, 2015). For sectors to receive the support it is essential to communicate the mitigation options available and publish research, to enable informed policy making.

The importance of identifying appropriate metrics and forecasts for the mining sector in South Africa is clear. The mining sector is an integral part of the South African economy. Mining was the second most influential industry in 1980, with its 21% contribution to the gross domestic product (GDP). In 2016, the industry still contributed 8%. However, the mining sector is still an important employer. The size of the mining workforce in 2015 was estimated at 490 146 individuals, according to Stats SA's recent census of mining report3. Gold mining, as a subsector, is the highest both in terms of competitiveness and export intensity (Harald Winkler et al., 2010). Apart from being export-intensive, mining is particularly energy intensive and would, therefore, require policies that still protect the employment while decarbonising. Accurate forecasting and target setting models and tools are, therefore, essential in developing and implementing decarbonisation policies. This analytical technique has successfully been applied for two mining companies and could be used in improved target setting and decarbonisation of mining companies with similar characteristics.

The target contained in the energy efficiency accord, and signed by the companies, was not clear. Depending on which intensity metric is used the absolute reduction would change. This is within the context that, whatever metric is used, the difference between the BAU and the target would be 15%. The implication is that tracking progress against such a vague commitment is difficult. Any future target or commitment should clarify which metric should be used. Preferably the metric closest linked to the activity associated with GHG emissions.

6. Application of the model on cities

6.1. Introduction

The decarbonisation trajectories of cities are linked to the implementation of national commitments and voluntary target-setting commitments under the Global Covenant of Mayors. The C40 Cities Climate Leadership initiative and the Global Covenant of Mayors is supported by four metropolitan cities in South Africa: Johannesburg, eThekwini, Tshwane and Cape Town. Under the C40 initiative these cities use the Global Protocol for Community-based Greenhouse Gas Emissions Calculations, an accounting and reporting standard for cities. However, the lack of activity data to calculate the inventories hamper updates and the reduction associated with mitigation actions are not well reported. Despite these challenges these cities have set and published GHG reduction targets, demonstrating the political will to integrate into the international economy and share ideas of global environmental responsibility (T. Lee, 2013).

Within a developing country context with rapid urbanisation, but limited data, tracking the GHG inventory against the targets is challenging. This research looks at four cities in South Africa that made GHG reduction commitments and supplied inventory data into publicly available databases (“C40 Cities Climate Leadership Group,” 2017). The cities are in different climatic zones of South Africa (see table 6-1 below), each contributing over 20% to the national GDP and are classified as metropolitan cities with more than one million citizens each.

Table 6-1 Climatic zones of four South African cities

Climate condition and zone	City
Cold interior	Johannesburg
Temperate interior	Tshwane
Temperate coastal	Cape Town
Sub-tropical coastal	eThekwini

Source: South African National Standard SANS 2014:2011, Energy efficiency in buildings

The respective GHG data is extrapolated based on official populations data from national census and socio-economic studies. The Gini index or Gini coefficient is a statistical measure of distribution developed by the Italian statistician Corrado Giniin in 1912. In economic it is often used as a gauge of economic inequality, measuring income distribution and, therefore, wealth distribution among a population The Gini coefficient is a commonly-used measure of income inequality that condenses the entire income distribution for a country into a single number between 0 and 1: the higher the number, the greater the degree of income inequality. With a Gini coefficient of 0,65 the South African society is extremely unequal. This inequality impacts the calculations of per capita emissions for the portion of the citizens where basic services are not yet provided Poverty is not sustainable. With the commitment, in 2016, to the Sustainable Development Goals, it reinforced the national programme on basic services and creating work for the unemployed of a workable age (Harald Winkler & Marquard, 2007). The decarbonisation trajectory has and should include sustainable development.. To achieve the Sustainable Development Goals, if no additional action is undertaken, GHG emissions will likely increase as the cities aim to provide universal access to modern sanitation, solid waste removal, electricity and mobile transport. This study looked at the additional GHG emissions that would occur if basic level of drinking water, electricity and sanitation was available to every citizen of the four metros. In addition it evaluated the additional emissions if all the citizens unemployed of a working age used the current transport infrastructure. Increased emissions due providing basic services to all in order to improve the human development index, and increased transport emissions due to citizens travelling to places of employment will increase the GHG inventory. Despite the justifiable reason for the increase this may still reflect negatively on these growing cities, who may be viewed as not taking enough climate action. The consideration of this issue was about data available and the data required to make decisions. Different departments in a municipality are involved in providing the different basic services, or dealing with implementation of climate action. The targets were set and announced on yet another level within the same municipality, around 2015/2016. This would mean that the same people involved in setting the target are not necessary the same that need to implement and coordinate climate action.

These cities have, however, already implemented a range of mitigation actions including: landfill projects, energy efficiency programmes, and bus rapid transport systems that continue to reduce emissions. The ex-post methodological approach is tested to present the GHG inventory together with the implemented mitigation initiatives in order to construct a counterfactual baseline on one climate action infographic.

The city analysis is done against the same categories for climate mitigating actions of a similar evaluation in Queensland, Australia (Zeppel, 2013) namely energy, water, waste, behaviour and offsetting. Due to the restricted data availability and the immature offsetting market in South Africa, the offsetting is set at zero for all the four metros. For behaviour change the 2016 Community Survey quantified a surprisingly high percentage of awareness and action on energy efficiency such as switching off lights and using blankets instead of heaters. However, in terms of the actual mitigation aspect, only the number of households who installed solar geysers are included as behaviour change. This limitation may result in a conservative estimate.

An important source of metropolitan specific data is the 2016 Community Survey, the second intercensal survey in democratic South Africa. This household-based survey is one of the few available data sources providing data at the municipal level. Municipal data supports evidence-based decision making which is best practice that many countries, including South Africa, embrace. Community Survey 2016 results supports optimal resource allocation and utilisation in all spheres of government in order to reduce poverty and vulnerability among South Africa's most marginalised. Secondly, the development and implementation of policy, implementation of the legislature deems it necessary to have reliable statistics that inform the social, demographic and economic standing of the country. Most of the city data for this research comes from a series of publications generated from the recently conducted Community Survey 2016 of Statistics South Africa. Statistics are disaggregated at a municipal level based on the 2016 municipal boundaries. All indicators of the community survey data are compared with Census 2011, where data for the latter are aligned to the 2016 municipal boundaries. The survey covered many themes, including population demographics, education, disability prevalence, parental survival status, access to basic services and how households rate services, food security, crime and safety. In this paper, only the populations numbers and access to basic services are used.

The employment data is obtained from the Quarterly Labour Force Survey quarter 4 2016 (Statistics South Africa, 2017a). The South African Quarterly Labour Force Survey is a household-based sample survey conducted by Statistics South Africa. The survey is focused on the labour market activities of individuals in the 15-65 year age category, who live in South Africa. The sample size of the survey links to the design of the 2011 national census and is representative at provincial level and also within provinces at metro and non-metro levels. Within each metro, the sample is further distributed by geographical type. The three geography types are Urban, Tribal and Farms. This implies that within a metropolitan area, the sample is representative of the geography of the metropolitan area. The definition of the unemployed are those in the age group of 15-64 years who:

> “a) Were not employed in the week of the survey, and
>
> b) Actively looked for work or tried to start a business in the four weeks preceding the survey interview, and
>
> c) Were available for work, i.e., would have been able to start work or a business in the reference week, or
>
> d) Had not actively looked for work in the past four weeks but had a job or business to start at a definite date in the future and were available. “ (Statistics South Africa, 2017a)

6.2. Reliability of the national survey estimates

Statistics South Africa is an independent government entity, and the Statistician General signs off on all national statistics reports. National statistics reports are developed based on figures obtained from estimates. Figures that would have been obtained from a complete enumeration of the population can differ from estimates, even when using the same instrument, since estimates are based on sample data. Results are, therefore, subject to both sampling and non-sampling errors. The non-sampling errors include biases from inaccurate reporting, processing, and tabulation, as well as errors from non-responses and incomplete reporting. These types of errors cannot be measured readily. However, to some extent, Statistics South Africa minimises non-sampling errors through the procedures used for data collection, quality control, editing, and non-response adjustment. The variances of the survey estimates are used to measure sampling errors (Statistics South Africa, 2017a).

It is useful to assess the size of the standard error relative to the magnitude of the characteristic being measured. The standard error is defined as the square root of the variance. The coefficient of variation provides such a measure. It is the ratio of the standard error of the survey estimate to the value of the estimate itself expressed as a percentage. The coefficient of variation for the unemployment value in the four metropolitan cities is 4,9% for Cape Town, 4,6% for Johannesburg, 6,7% for eThekwini and 8% for Tshwane.

The method for estimating variances in the Quarterly labour force survey is the Fay Balanced Repeated Replication (BRR) method (Judkins, 1990) because of its simplicity. The p-value corresponding to an estimate of change is the probability of observing a value larger than the particular observed value under the hypothesis that there is no real change. If p-value <0,01, the difference is highly significant; if p-value is between 0,01 and 0,05; then the difference is significant; and if p-value >0,05, the difference is not significant. The p-value, indicating the significance of variance of the underlying unemployment is 0,01 for Cape Town, 0,071 for Johannesburg, 0,00 for eThekwini and 0,09 for Tshwane. Therefore, the difference is highly significant for Cape Town and eThekwini and not significant for Johannesburg and Tshwane.

The emission reduction achieved by implemented mitigation initiatives of each of the cities areobtained from two independent studies performed in 2014 for the Department of Environmental Affairs. Both studies evaluated the impact of mitigation on the national GHG inventory. One study evaluated the impact of waste initiatives on the national GHG inventory (Shachar et al., 2016), while the other study evaluated the impact of the national public transport strategy of 2007 (CSIR, 2016). Both studies followed the methodology of the World Resource Institute's GHG Protocol Policy and Action Standard (World Resources Institute, 2014b).

6.3. Mitigation actions in the transport sectors

The transport sector is the second most significant source of GHG emissions in the energy category of the GHG inventory of South Africa, accounting for 453 924 Gg CO_2 eq from 2000 - 2010 (Department of Environmental Affairs Republic of South Africa, 2014). This sector is dominated by road travel, with a higher than the world average of private car ownership (Department of Environmental Affairs Republic of South Africa, 2013b). In 2010, road transport contributed 91.2% towards GHG emissions of the transport sector, and this is expected to increase as urbanisation and private motorization increases (Department of Environmental Affairs Republic of South Africa, 2013b). The benefits of supporting sustainable transport systems not only contributes to addressing the impacts of climate change, but the impacts on cities and citizens themselves by improving air quality, reducing noise from traffic, increasing road safety, reducing road congestion, improving international competitiveness, increasing access to urban transport, reducing travel costs for society, and creating employment opportunities. The overarching national policy in the transport sector in South Africa remains the national public transport strategy of 2007 (Walters, 2013). While the Strategy was not designed specifically to mitigate GHG emissions, it does reduce them. The implementation of sustainable transport strategies is a new paradigm in South Africa aimed at countering the impacts of the prevailing transport trends on society and the environment. Since the deregulation of public transport in 1986, the movement of people has increasingly taken place using smaller vehicles with an increasing trend in private car use and the consequent decline in mass public transport modes. Figure 6.1 shows a plot of the vehicle and the human population in South Africa normalised to 1965 figures. The data indicates that the vehicle population growth rate is growing at 2.7 times the human population.

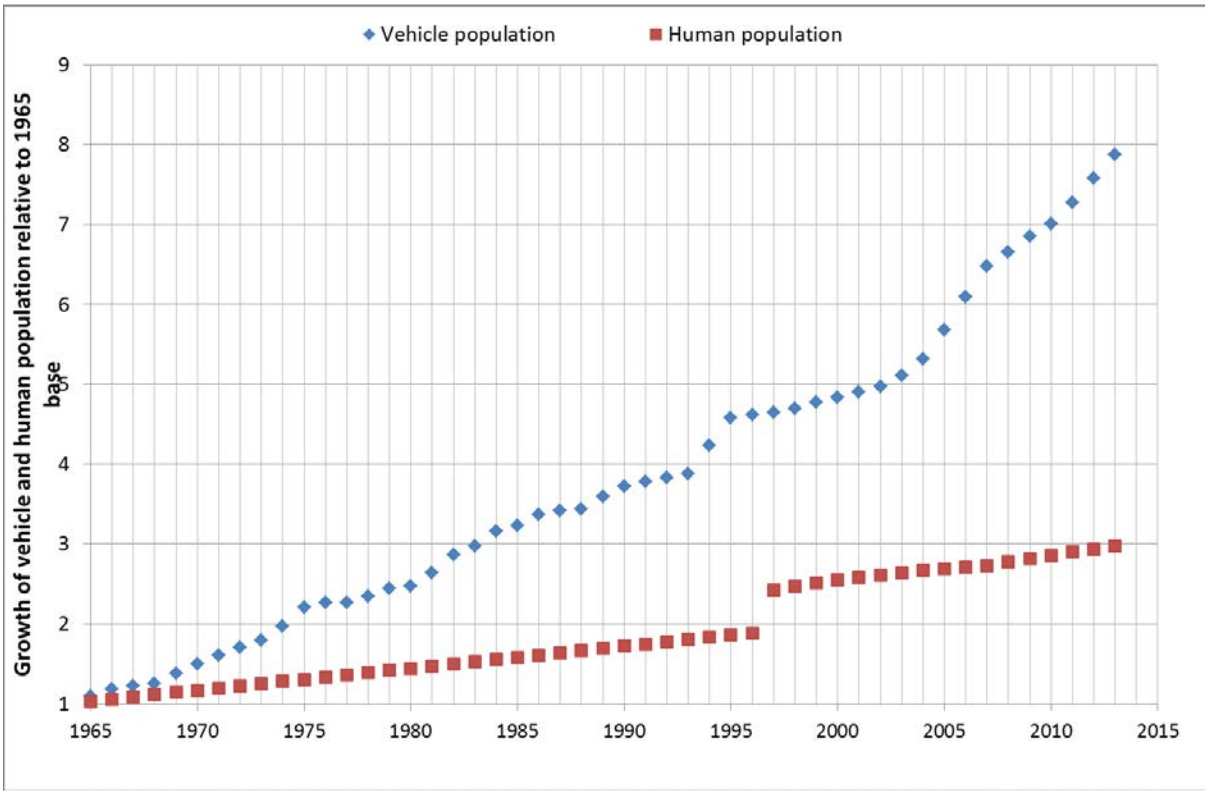

Figure 6-1 South Africa's human and vehicle populations

Source: (CSIR, 2016)

This trend is problematic considering the increase in GHG emissions from the transport sector as the population grows.

The implementation of the public transport strategy takes place under the auspices of the National Land Transport Act (Republic of South Africa, 2009). Regarding this Act, all spheres of government are collectively responsible for delivering customer responsive public transport services and infrastructure. The national sphere of government provides an appropriate policy environment and supporting mechanisms. Functions related to public transport include a national policy for public transport, funding of public transport, regulation of interprovincial public transport and tourist transport and coordination between spheres of government. The provincial sphere of government primarily sets and implements province-specific public transport policy. The local sphere of government is primarily responsible for the formulation of the municipal Integrated Transport Plan and its full implementation. Therefore, while the public transport strategy is formulated nationally, its implementation is in the local sphere of government. The following interventions are already implemented in various cities:

- Bus Rapid Transit Projects and Taxi Recapitalisation,
- Improvement of existing rail and introduction of new rail lines and extensions,
- Improved land use planning, and
- Non-motorized transport infrastructure.

Improved integration of transport and land-use is a legal requirement for all municipalities in South Africa under the National Land Transport Act (Act 5 of 2009). Land-use strategies implemented in South Africa are broadly categorised as either densification and mixed-use or transit-oriented development. However, the improved land use planning intervention is relatively difficult to measure, is not monitored and is, therefore, excluded. There is also poor data collection of usage of non-motorized transport initiatives and mode shift, and thus the impacts from these initiatives can not be estimated and, therefore, are also excluded.

In South Africa mass transit projects are being rolled out in eight metropolitan cities based on Integrated Rapid Public Transport Network plans. Projects with significant operations are the Cape Town and Johannesburg BRT projects. MyCiti and Rea Vaya as well as the Gautrain Rapid Rail link in Gauteng province. These projects have been in operation since approximately 2009 thus creating a reasonable assessment period for analysis. The A Re Yeng in Tshwane had limited services during the period (2007-2014) but is currently operational, while Go Durban is under construction (CSIR, 2016).

The Gautrain Rapid rail link started operations in 2010, and is a high-speed rail system connecting Tshwane, Johannesburg, OR Tambo International Airport. Metrorail launched five business express services in Johannesburg and Cape Town from 2007 to 2009. The services are listed:

- The Soweto Business Express linking Soweto to Johannesburg in 2007,
- The Khayelitsha Express connecting Khayelitsha to the City of Cape Town in 2008,
- The Tshwane Business Express in 2008 that links Tshwane to Johannesburg,
- The Cape Town Premium Express connecting Strand to the City of Cape Town in 2009, and
- The Gauteng business express that connects Tshwane and Johannesburg in 2009.

This research has allocated the GHG emissions according to either the trip distance and the proportional rail connection located in each metropolitan city.

The Taxi Recapitalisation programme provides a once-off scrapping incentive for taxi owners to receive newer and safer taxi models. The aim of the programme was focused on improving safety. However, upgrading the taxis to newer vehicles would also have GHG benefits linked to the fuel efficiency improvement. This programme is referred to in Public Transport Strategy as a modal upgrade under the Implementation of Integrated Rapid Public Transport Networks. The GHG emission saving from the taxi recapitalisation programme is allocated to the cities based on the GDP contribution of each metropolis to the national GDP, which is: 24% for Cape Town, 34% for Johannesburg, 22% for eThekwini and 20% for Tshwane (Statistics South Africa, 2018b).

6.3.1. Life cycle emissions of transport projects

Direct GHG effects also occur during the construction phase of public transport projects. As the construction phase occurs over the short term, the GHG effects are also short term. Emissions occur during the construction of public transport infrastructure due to the combustion of fuel used in machinery and equipment, electricity consumption from offices and electrical equipment and product use including cement and bitumen used. Previous studies conducted by Cui et al.(2010) and Melanta, Miller-Hooks, & Avetisyan (2013), show that emissions from construction are important sources of GHG emissions. As such, construction GHG emissions are included in the GHG assessment boundary for transport projects. Construction activities contribute to traffic congestion and to idling GHG emissions of road transport. However as the duration of traffic congestion is short and localised, the GHG emissions are relatively small. The GHG emissions from idling vehicles are, therefore, excluded from the GHG assessment boundary.

Upstream activities from manufacturing of vehicles, equipment and construction materials are also important contributors to GHG emissions (Cui et al. 2010). However, while some manufacturing activities occur within South Africa, others take place overseas, and, therefore, GHG emission from manufacturing activities are not included in the GHG assessment.

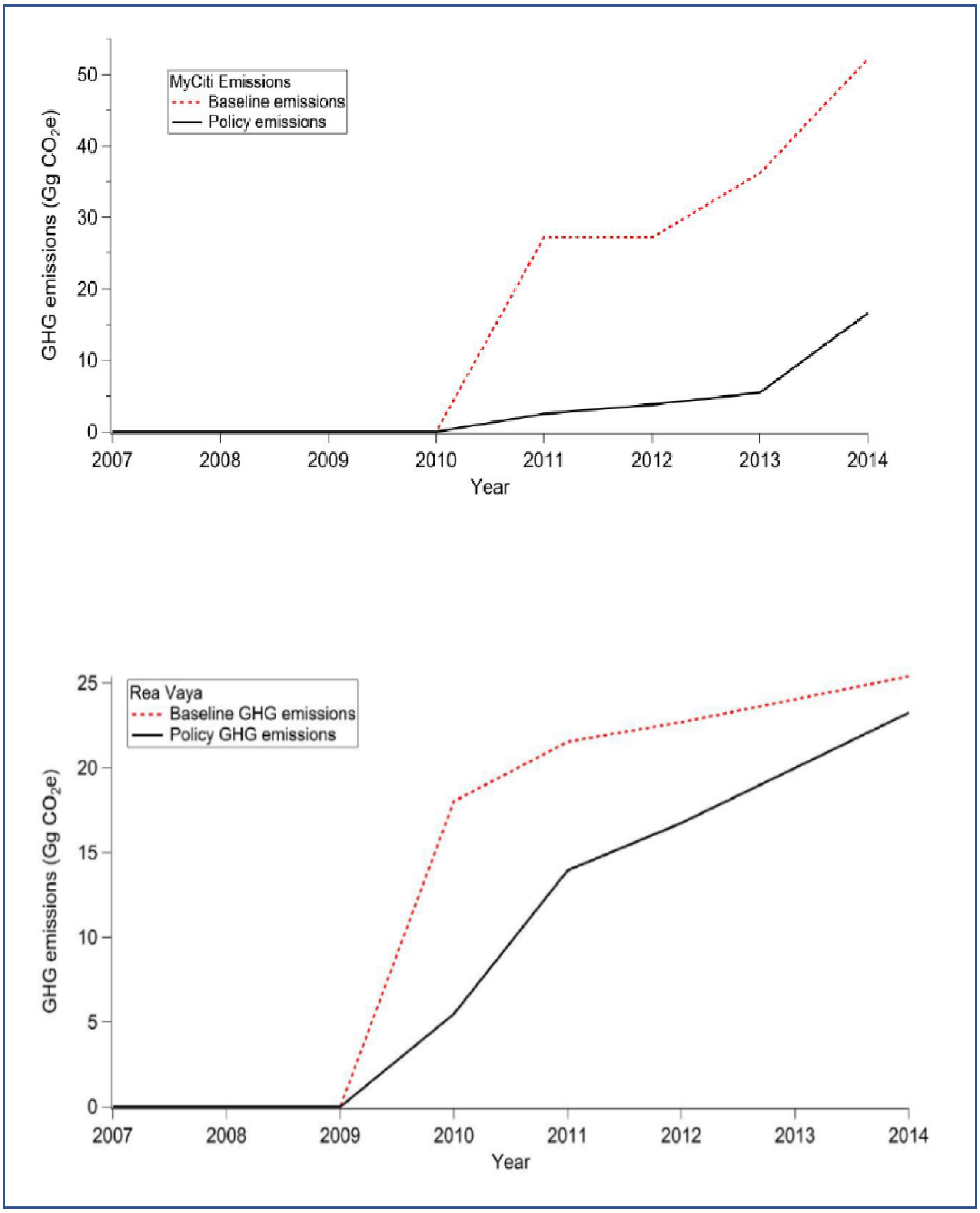

Figure 6-2 The ex-post calculation of the baseline and the implemented bus related policy initiatives associated with the 2007 National Transport Strategy

Source: CSIR 2016

The different trajectories of the baseline scenarios in the graphs above are caused by the assumptions on total vehicle kilometres travelled for the taxi fleet versus cars. The *MyCiti* baseline assumed a higher car to taxi kilometres in the city of Cape Town than the *Rea Vaya* baseline, which assumed equal car and taxi kilometres in Johannesburg. These assumptions were based on data obtained from the Southern African Bus Operators Association SABOA and the South African National Taxi Council (SANTACO). However, the CSIR concluded that there is a need for surveys to understand the drivers between these differences (CSIR, 2016) .

6.4. Mitigation actions in the waste sectors of cities

Globally, post-consumer waste contributes a relatively minor proportion of total GHG emissions (less than 5% in 2005), while methane from landfills accounts for 12% of global methane emissions (Hoornweg & Bhada-Tata, 2012). However, the potential of the waste management sector to contribute to the reduction of global GHG emissions spans further than these figures suggest. Improvements in waste management that prevent and recover waste streams present significant opportunities to reduce emissions by reducing material and fossil fuel demand in other sectors of the economy including energy, manufacturing, transport, and agriculture (UNEP, 2011). Therefore, the net climate change mitigation effect of waste management practices must also take into account both the direct greenhouse effect of the waste management process, in terms of avoided landfill emissions, and indirect effects, such as the impact on energy consumption, effects on transport, demand for virgin resources in manufacturing, or the sequestration of carbon into the soil from composting (UN Habitat, 2010).

South Africa’s National Waste Management Strategy presents a long-term national plan for addressing key issues, needs, and problems in the South African waste management industry through a move towards integrated waste management (Department of Environmental Affairs Republic of South Africa, 1999). The focus should be on the entire waste cycle including the prevention, generation, collection, transportation, and final disposal of waste. The research builds on an ex-post assessment of the GHG impact on the National Waste Management Strategy for projects that were operational between 1999 and 2014 (Shachar et al., 2016).

PETCO (PET Recycling Company NPC) was established in 2004 as the South African self-regulation of post-consumer polyethylene terephthalate (PET) recycling (PETCO, 2017). Data is published annually and the level of uncertainty is considered to be low, as it is below 20% (Shachar et al., 2016). The GHG reduction associated with national recycling savings are allocated to each city based on their prospective contribution to the GDP of the country.

TGRC (The Glass Recycling Company) was established to promote glass recycling in 2006 (TGRC, 2015). TGRC operates throughout South Africa but it does not physically collect or process glass recyclables. TGRC is a voluntary industry initiative supported by 22 shareholders and is funded exclusively by the levies paid by these brand owners for every ton of glass purchased from the glass manufacturers . TGRC activity data is published annually and the level of uncertainty is considered to be low, as it is below 20% (Shachar et al., 2016). The GHG reduction associated with national recycling savings are allocated to each city based on their prospective contribution to the GDP of the country.

While the South African biogas industry has existed for a number of years, it remains small. As of April 2016, there were 38 projects operational in South Africa, but half have been decommissioned due to a low carbon price (Ekelund & Nystrom, 2007), (Shachar et al., 2016). These projects utilise organic waste which is fed into anaerobic digesters and converted into biogas to generate heat and/or electricity. This displaces low-cost coal-based electricity from the grid. Municipalities across South Africa implemented projects with the intention of extraction and destruction of landfill gas, thereby reducing GHG emissions and obtaining carbon credits. Flaring is the most common method of destruction, however, landfill gas can also be used as an alternative to natural gas for the generation of heat and electricity, or it can be upgraded for use as vehicle fuel. Monitoring for the Clean Development Mechanism provides good quality mitigation information as each project location is available and GHG mitigation is verified. Only those within the respective metropolitan city boundaries, therefore, are identified and are used in the case studies.

Regarding composting, there is a lack of information and monitoring from composting facilities throughout South Africa. Therefore only data from a commercial composting facility could be used. *Reliance* is a commercial scale composting facility located in the Cape Town municipality – and is, therefore, included in this research. A monitoring report according to CDM methodology is drafted and independently verified (Wylie, 2010) and the carbon credits are sold on the voluntary market.

A materials recovery facility (MRF) is a specialised plant that receives, separates and prepares recyclable materials for marketing to end-user manufacturers. MRFs are essentially materials reclamation and recycling facilities with the purpose of re-using and recovering recyclables from waste and diverting it from landfills. There are two operational MRF facilities in Cape Town (Shachar et al., 2016). These are included in the Cape Town municipality case study.

6.5. Mitigation action in the energy sector of cities

There is a lack of clarity in financial savings reported by public entities about energy efficient interventions. This makes it difficult to quantify the energy savings or benchmark the energy usage patterns of the public buildings of each city.

In South Africa, the metropolitan cities are well connected into the Southern African Power Pool, of which Eskom, the South African energy generator and distributor is the most significant contributor.

The increase in grid connected electricity prices and the simultaneous decrease in the cost of Photo Voltaic systems has resulted in an increased number of pilot projects for off-grid, on-site power generation, Unfortunately there is no reliable data on the roll-out tempo in South African cities as the power can only be used on site, as regulations have restricted the possibility of feeding to the grid in most municipalities (de Jongh, Ghoorah & Makina, 2014). On-site energy generation is, therefore, not added as mitigation actions in any of the city case studies.

In the latest community survey from Statistics South Africa, energy efficiency initiatives within communities and also cities were collated (Statistics South Africa, 2018b). These included households switching appliances off, boiling only the water that is needed, closing windows in cold weather, drip drying of clothes, installing energy saving bulbs, insulating geysers, installing solar geysers, switching off lights when leaving the house and wearing warmer clothes instead of using a heater. The impact of the awareness and lifestyle change is difficult to quantify, as it depends on the baseline of each household. Quantifying the energy saving linked to these energy efficiency initiatives would require additional surveys or information about the baseline, the type of equipment, the size of the dwelling and the number of rooms in a household. Only the solar water heaters installed in the households, assuming one per household, are included as a mitigation initiative, as the GHG emission reduction can be quantified, through the solar water heater performance data (Donev et al., 2012), (Eskom, 2011).

6.6. Greenhouse gas inventory data from four metropolitan cities

The GHG trajectories of cities, in accordance with the GPC methodology, are available for four South African metropolitan cities on the C40 website. The breakdown of the three main contributing sources to a city's inventory, energy, waste and transport, are extrapolated historically based on the official population statistic in 2011 and into the future depending on the city's own forecasts which is either 2020, 2021 or 2023. This is complemented with the commitments for the provision of basic services and meeting the sustainable development goal in the form of suppressed demand from 2016. Although basic services have already beenprovided in all the cities, to a limited extent, since early 2000, the date of 2016 was chosen for two reasons. Firstly this is the year that the commitment for meeting the sustainable development goals was made public and secondly, the data was available through the national community survey for each city.

Table 6-2 Unserved basic services and unmet development goals of households in four South African cities

Cities	Households with no access to clean drinking water	Households with no access to sanitation	Households with no access to any form of refuse removal	Households with no access to electricity for lighting	City citizens unemployed
Cape Town	6,3%	0,8%	0,6%	2,4%	12,5%
Johannesburg	5,9%	0,3%	2,4%	8,7%	17%
eThekwini	9%	0,8%	1,7%	3,6%	12%
Tshwane	9,6%	0,6%	2,6%	3,8%	16%

Source: Statistics South Africa data from the 2016 Community Survey

Each city's GHG emissions inventory are, therefore, adjusted as if:

- every citizen had at least 50 litres of drinking water per person per day,
- access to sanitation infrastructure and
- modern energy, while
- every currently unemployed person increased the current transport emissions proportionaly in order to generate a basic income.

The provision of water and sanitation is a fundamental right for all South African and is enshrined in the Bill of Rights, within the Constitution of South Africa (The Government of South Africa, 1996). Providing basic services supports the following seven of the 17 Sustainable Development Goals for 2030:

Goal 1 End poverty in all its forms everywhere;

Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture;

Goal 3: Ensure healthy lives and promote well-being for all at all ages;

Goal 6: Ensure availability and sustainable management of water and sanitation for all;

Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all;

Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all, and

Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable. (United Nations, 2017)

For each household, the 50kWh of basic electricity and refuse removal is calculated based on the current energy emissions associated with households that are connected, as well as the waste emissions associated with the percentage of households that are currently serviced with waste removal. The increase of GHG emissions due to the additional provision of water and sanitation to citizens, currently unconnected, is taken as an propotional increase of the energy consumption of the municipal utilities to the currently serviced city population. The household calculations also includes the official reduction values of household sizes in each city between 2011 and 2016, as presented in table 6.3.

Table 6-3 Household sizes in four South African metropolitan cities

City	Official household sizes	
	2011 National Census	2016 National Community Survey
Cape Town	3,5	3,2
Johannesburg	3,1	2,7
eThekwini	3,6	3,3
Tshwane	3,2	2,9

Source: National Statistics South Africa, 2011 National Census and 2016 National Community Survey

Due to poverty-related absences of emissions,the greenhouse gas inventory of each city is too low. This is corrected through an adjustment on meeting basic services and transport towards places of employment. The largest contributor in this adjustment, exceeding 90%, is transport for the currently unemployed to travel towards a place of employment. The contribution ranged from 90% in Tshwane to 95% in eThekwini. These results indicate the importance of focusing the priority of cities on low carbon transport infrastructure to ensure a long-term sustainable future for all citizens. The impact of the provision of basic services, such as clean water, sanitation, modern energy and refuse removal on the respective GHG inventories of each city is less than 10% of the suppressed demand.

The graphical representation of the four city inventories, extrapolated to cover the 2011 to 2020 period, and expanded to include suppressed demand for basic services, is presented in Figure 6.3.

Figure 6-3 Inventories extrapolated for the 2011 to 2020 period and expanded to include supressed demand for basic services

6.7. The impact of mitigation actions on the city's greenhouse gas inventories

Mitigation actions implemented within the city boundaries can reduce the GHG inventory of the city. The mitigation initiatives are added to the expanded GHG inventory (including the suppressed demand for basic services from 2017). Only reductions from implemented projects, mentioned in public documentation are included in each case study.

Figure 6-4 Mitigation actions and the GHG inventories to show the counter factual baselines of each city

The cumulative impact of GHG mitigation undertaken over a longer period (>4 years, which is one local government election cycle) is visible in the Cape Town and eThekwini inventories as these cities had, in recent years, stable city management. Both Tshwane and Johannesburg experienced complex changes in city management and vision over the last decade and, therefore, although plans are developed and approved, these are not yet implemented and subsequently not reducing GHG emissions.

All four cities committed to ambitious GHG targets:

- Johannesburg: 40% below 2007 base year by 2040
- Cape Town: 13% reduction below baseline scenario
- eThekwini: 26% reduction from 2010 base year
- Tshwane: 50% intensity reduction per citizen from 2014 to 2018

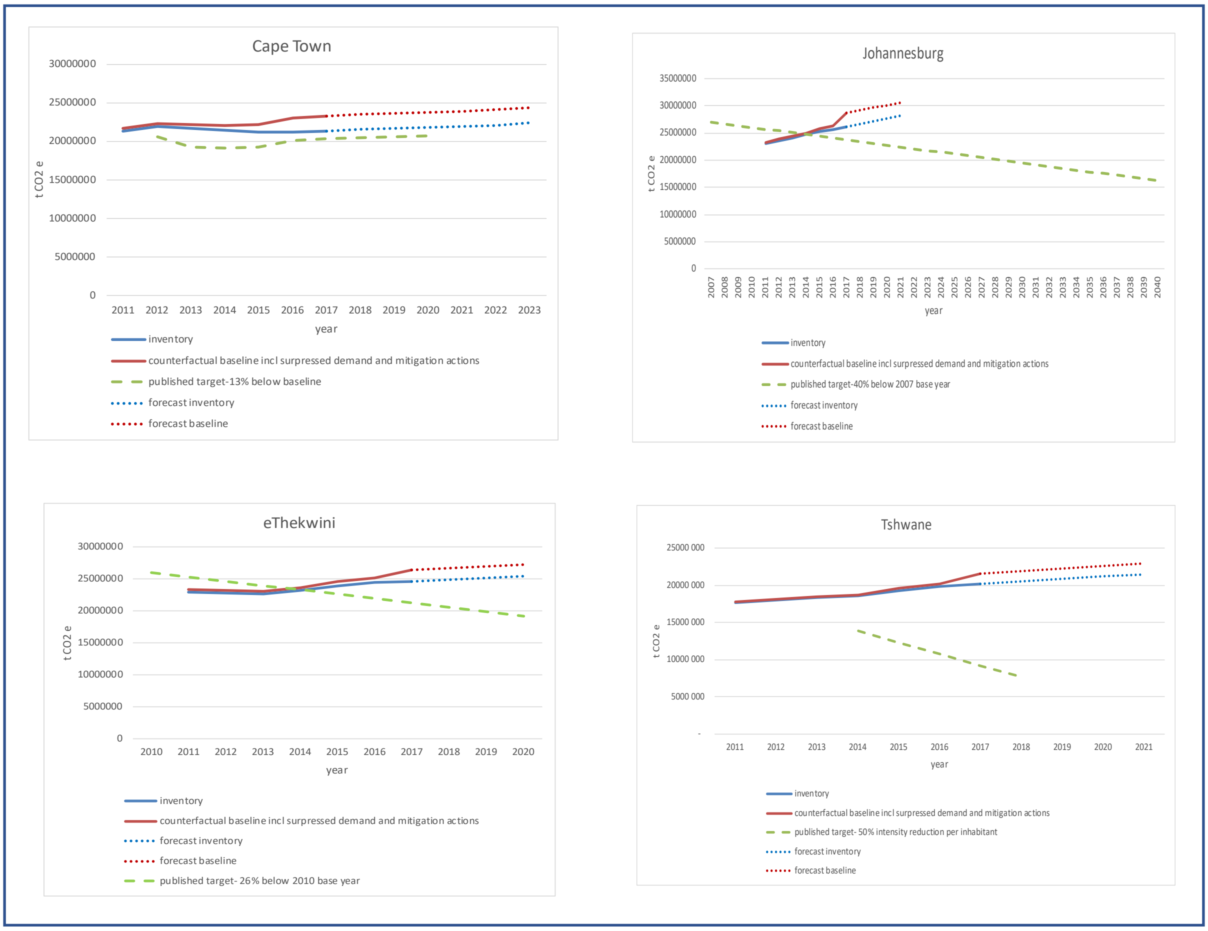

Figure 6-5 City targets against the greenhouse gas forecasts and counterfactual baselines

With the current set of mitigation initiatives all four cities are unlikely to meet their ambitious self-imposed targets. The trend for Johannesburg and Tshwane, and to a lesser extent eThekwini, is a progressive widening of the distance to target. Only Cape Town has a trend that is narrowing the gap. This is partly due to a larger number of initiatives, but also due to the cumulative benefit of having implemented projects already five years ago.

The type of target for a city with a fast and unknown population growth makes absolute targets difficult to meet with a limited budget. A cost-benefit analysis is however outside the scope of this study. An intensity target or target as a percentage below the baseline would be easier to monitor and would provide a fair reflection of the impact of mitigation actions in a growing city context. Meeting the demand for basic services, as stated in the Sustainable Development Goals, should be included in the base year and calculated as part of setting a GHG target.

6.8. Conclusion on the applicability of the analytical technique for cities

The ex-post methodology creates a counterfactual GHG baseline, using two existing data sets, to derive the distance from the target. The first set of data is the actual emissions of the cities, extrapolated to a continuum over time and based on population numbers. This information is available in the public domain as national statistics. The second set of data is implemented emission reduction activities and the actual emission reductions achieved over time to reduce either energy consumption or GHG emissions. The counterfactual baseline is the sum of the GHG emissions and the achieved emission reductions. This would be the theoretical emission trajectory for each city if the emission reduction activities were not implemented.

The importance of monitoring, and keeping records, of implemented GHG mitigation initiatives has been highlighted. The trade-offs in dealing with unmet development goals can be calculated in this analytical technique. However the impact of this trade-off is that more GHG mitigation initiatives would be required to meet the GHG targets. The GHG target itself in a developing country with significant unmet sustainable development goals, should be carefully formulated. Suitable targets are formulated in terms of intensity, or a percentage reduction under the counterfactual baseline. An absolute reduction target is less ideal and monitoring against such a target should include changes in boundaries and population numbers. This analytical technique has been applied on four South African cities to develop one climate action infographic for each city and could be used in improved target setting and decarbonisation of cities with similar characteristics.

7. Conclusions, implications, and recommendations

7.1. Introduction

Chapter 6 concludes this research on GHG emissions, climate actions and target setting. As covered in Chapter 1, the background of this research is the global levels of GHG emissions that are still increasing and despite the successful negotiation of an international agreement in Paris, detail about the decarbonisation trajectory is not yet clear. Many countries, including South Africa, have already taken climate action and have committed to a National Determined Contributions. Energy-intensive companies, such as gold and iron ore companies, have also signed an energy efficiency accord, committing to GHG reduction between 2005 and 2015. Cities are already participating under the Covenant of Mayors in committing to ambitious voluntary GHG reduction targets. The problem statement is that the current GHG reporting structures do not support effective GHG target setting or tracking of performance. In the literature, covered in chapter 2, it was shown that reporting of policies and actions is complex, but that GHG inventory reporting is improving on all levels of private and public sector. However, improved reporting does not mean improved mitigation, and growth in GHG emissions might undo the reduction in GHG emissions from projects. Forecasting is a science based on extrapolating specific metrics or activity data. However, forecasting is also based on different methodologies, boundaries and other factors, often not well quantified or made public. The aggregated national contributions under the Paris Agreement do not yet meet the objective of keeping the global average temperature increase below 2^{0}Celcius, and additional GHG mitigation is required. There is an increase in published peer-reviewed articles on possible deep decarbonisation pathways and proposed sectoral or regional trajectories that could meet the objective. These are based on the latest national GHG inventories and impact of possible mitigation actions. There are, however, uncertainties in the national GHG inventories and the impact of the mitigation actions. Transparency of mitigation actions is required to conclude on the performance against targets to overcome some of the uncertainties in the inventories. Tracking progress against targets and goals is essential in moving towards a sustainable future (in which the sustainable development goals are also met) within a limited and shrinking carbon budget. Chapter 3 developed the ex-post analytical technique to evaluate the GHG inventories, restating the inventories if required, and presenting it with the mitigation action on one infographic. This analytical technique provides this climate action infographic that captures the progress against the target or commitments with a focus on the implemented mitigation goals. The elements of the analytical technique were described in section 3.2 and then applied to three different contextual situations:

- On a national level the GHG trajectory of South Africa is presented in chapter 4. The trajectory is developed by adapting an ex-post analysis on the South African national GHG inventory to demonstrate the impact of the voluntary GHG reductions already implemented, and the need for restating inventories to reflect the coal type consumed in the country. Chapter 4 provides both the GHG inventory for South Africa for 2000-2012 (figure 4-1) as well as estimations for the 2013-2017 period (figure 4-3), bridging the data gap with national Statistical data. The mitigation actions (figure 4-4) were presented together with the GHG trajectory to establish a counterfactual baseline. The GHG inventory was also presented against the upper and lower level of the national commitment to provide an overview of progress (figure 4-5).
- On a company level the GHG trajectory of both an opencast iron ore mine and an underground gold mine were presented in chapter 5. The trajectory was developed with forecasting of GHG emissions in the mining sector for GHG target setting, as a case study around the energy efficiency accord. The company-specific results were presented separately for the gold mining (section 5.1 and 5.2) and iron ore mining (section 5.3 and 5.4). The production forecasts and reduction targets were presented as Figures 5-4 and 5-8 respectively. The GHG inventories together with the impact of the mitigation initiatives to generate a counterfactual baseline were presented in Figures 5-5 and 5-9 respectively. The combined analysis of forecasts and targets against the counterfactual baseline and inventories were presented as figures 5-6 and 5-10 respectively
- On a metropolitan city level, the GHG trajectory for large cities in South Africa was presented in chapter 6. The GHG inventories and mitigation actions or each of the four South African cities was developed as a case study on filling data gaps and inspiring action through infographics. The unserved basic services were graphically represented as unmet development goals of the four cities (table 6-1). Through extrapolations and adjustments, the data gaps in time and in meeting the basic services related sustainable development goals were filled to derive at the GHG inventories for each of the four cities for the period 2011-2020 is presented as figure 6-1. The mitigation in each city was added to the GHG inventory to create a counterfactual baseline (figure 6-2). The published targets of each city were presented against the GHG inventory forecasts and counterfactual baselines (figure 6-3).

7.2. Conclusions about the research questions

The conclusion against the five research questions is covered in this section. Findings from the research as presented in chapter 4, 5 and 6 are explained and linked to previous research covered in chapter 2.

How can emission reductions from mitigation activities be distinguished from emission reductions from other external sources?

A reduction in the inventory is not always due to the implementation of mitigation actions. This can be seen in the European trajectory exceeding the Kyoto target (section 2.4 and figure 2.1) and the verified emissions inventory of Gold Fields (figure 4.5) meeting the energy efficiency target of 15% below the business as usual line. This reduction of emissions is not due to increased emission reduction activities, but due to a range of external and internal factors.

For the mining companies the three main factors that impacted both metrics are an increase in the grid emission factor, a decrease in ore grade and mining depth, and a decline in production. The gold produced was 65% less than forecasted, while the volume of ore milled 22% less, resulting in significantly fewer emissions than forecasted (see Figure 4.4).

External changes, such as the grid emission factor, impact on the actual GHG emissions of a company. An evaluation of the methodology behind the calculation of the grid emission factor (GEF) in South Africa during the same period, but using data covering three years: 2007/8, 2008/9 and 2009/10, showed significantly different approaches and results (Spalding-Fecher, 2011). The Spalding-Fecher evaluation proposes that a reasonable marginal GEF for these three years would have been 0.874, 0.905, and 0.909. These values are in line with the values that companies, cities and the country used in published GHG emissions data. Other studies did, however, caution on using an average CO_2 intensity of the national grid, in favour of determining the GHG intensity of the future power mix, to avoid over or under estimation of GHG emission savings when forecasting emission reductions against a baseline (Harmsen & Graus, 2013).

The composition of liquid fuel is regulated in South Africa and therefore, the emission factor for fuel remains constant and does not effect the GHG calculation over time. Reducing the GHG emissions associated with the combustion of liquid fuel would require either an efficiency improvement or a move towards biodiesel with a lower emission factor.

Only direct reporting on the emission reduction associated with the mitigation projects will provide the required awareness as there are, over time, many external factors that influence the GHG inventory.

What can be learned from a decade of emission forecasting that can be useful in target setting?

Methodologies for GHG reporting in terms of boundary setting and emission factors have become increasingly detailed and prescriptive. Prescriptive methodologies support benchmarking and harmonisation of international reporting, and also reduce the risk of double counting within each reporting system. However, the double-counting risk, is not the only risk, and in dealing with the double counting risk, the process and focus on restatements become difficult and seemingly unimportant. This might not introduce material inaccuracies in the short term, but over a decade the forecasting process should enable restatements. These restatements require standardised methodology.

On a national level there is limited scope to change indicators, as it is prescribed as part of international GHG reporting requirements.

The results from the four South African cities case study are in line with the conclusions of the Swedish Energy Institute on the lack of consistent data on urban GHG emissions, and that results in cities' GHG studies that should be interpreted with caution, and that more research is needed (Erickson, 2015). Still, it is clear that significant GHG abatement opportunities are available to cities and effective tools are required to guide the transition towards lower carbon and climate resilient urban societies. Apart from mitigating GHG emissions now, they can lower the cost of future carbon reductions through innovative planning. Transparency and oversight on the transition and a mechanism to track progress against GHG targets could support funding applications such as the Global Environmental Fund or through donor agencies. Within a city context emissions per person is a suitable metric within the context of a growing population. While setting the target the poverty-related absences of emissions should be calculated and added, before setting the GHG target to allow for meeting the sustainable development goals as well.

For mining, three key factors have changed from 2005 to 2015 that impacted the actual reported emissions. The actual GHG emissions are linked to the grid emission factor (GEF), the actual production figures, and the influence of physical mining parameters, such as ore grade and mining depth. These factors influence the accuracy of the forecast estimations compared to the actual figures.

The GEF has increased since 2005. In 2005, Gold Fields had forecast the emissions based on a 2005 GEF of 0.835. However, in 2012 the GEF had increased to 1.03, impacting on the associated GHG emissions per unit of electricity consumed. The actual production (both in ounces of gold produced and tonnes of ore milled) deviated substantially from the 2005 forecast. Tonnes of ore milled increased annually from 2005 to 2015, while the actual ounces of gold produced reduced over the same period. With the unbundling of the company, the relevance of the forecast production values, for tracking progress, is reduced, as mine planning is linked to the revised strategic focus on high-grade ore mining and profitability. The results highlight the uncertainties in forecasting GHG emissions from the mining industry. Using these current forecasting practices, in setting GHG targets, is difficult and the planning or management to reach these targets have a limited chance of success.

The life stage of the mine impacts on the stripping ratio and should be carefully factored in when setting targets. The high GHG emissions associated with the initial development of the mine negatively affect the GHG inventory of these mines during the early years. As the mine reaches its end of life stage, the ore grade and increased distance from the pit to the processing plant result in increased energy consumption and associated GHG emissions. Within a voluntary commitment scenario, transparency on the GHG emissions from the life cycle stage of the mines in a mining portfolio would be sufficient. However, in a mandatory reporting system, a form of capitalisation of the emissions might be required to spread the emissions over the life of the facility.

For mining the ore grade and mining depth have significantly influenced GHG emissions. Both these physical mining parameters have impacted negatively on the energy consumption and associated emissions in South African operations.

A metric such as output production is only a single indicator of a mine’s performance and is affected by numerous other factors, and consequently, it is less appropriate for GHG forecasting or target setting. Using a metric linked to the activity within the operations, such as total tonnes milled or mined is more appropriate than using a metric of production output for mines, such as Kumba and Gold Fields. Since the tonnes milled metric has a higher accuracy, it would be a better metric for future intensity-based target setting for these mining operations.

How to deal with the challenges of matching information needed with information available?

In this research, it is found that there is a 20% over-reporting of primary energy emissions in the 2010 GHG inventory of South Africa (Figure 4). This error is linked to the use of a Tier 1 calculation methodology of the 2006 IPCC Guidelines for the national GHG inventory while Eskom has published the calorific values of the low-grade coal used to generate power. Countries dependent on coal for energy should ensure that the actual coal calorific values for the different coal types are used in the GHG inventories and where needed, the historic inventories must be restated.

While it is in accordance with the IPCC guidelines to correct errors and restate national GHG inventories, it can be complicated and it requires clear communication with all stakeholders. In contrast, the standard for corporate GHG inventories provides clear guidelines for a restatement of previous inventories as a basis for comparison and trend analysis. South Africa, India, and China are already refining and improving the coal values used in their respective national inventories.

The 2010 national inventory of South Africa should be restated for the 20% difference between using the default coal calorific value, and the reported the calorific value of coal combusted for electricity generation before the government uses it as a policy instrument for reducing industrial GHG emissions in the form of fixed company specific carbon budgets. The revised downward values were subsequently used in the sectoral mitigation potential analysis. However, in 2016 the original erroneous inventory values were again used as a basis for the first national annual climate change report published in 2016.

In India, refinement of sector-specific calorific values for coking- as well as non-coking coal and lignite used for various industries from 2010, is underway, which will impact on the national inventory (Ministry of Environment Forest and Climate Change, Government of India, 2015).

Apart from investigating the calorific value of coals consumed in key Chinese sectors by type and purpose, changes in economic structure and policy will result in significant changes in the projected emissions trajectory to 2030 (Grubb et al., 2015). Therefore, monitoring systems are being put in place to accurately track emissions and update forecasts.

Restating the emissions will add complications in tracking progress against the commitments made under the Paris agreement. However, the benefit would be realistic emission estimates and a focus on actual mitigation actions. Provisions in the Paris Agreement require countries to regularly review, update and strengthen these actions. A flexible approach is required in tracking progress within the limitation of uncertain emissions inventories as a departure point. If the emissions of land-use, land-use change and forestry is included the uncertainty of all emission inventories will increase again due to the nature of this emission category (Rogelj et al., 2017).

Transparency is thus key in the journey to the low carbon economy. Other souces of public data, if referenced, can be used to fill data gaps in order to cover a long time period or include more mitigation actions. From this paper it has been demonstrated that a climate action infographic can be constructed for cities, companies and the country despite data gaps. Filling data gaps in an inventory is important but should not take priority above implementing GHG mitigation actions.

When can the progress evaluation against the emission reduction target be misleading?

GHG target setting can take various policy forms. Under the current international climate change negotiations, countries might propose respective national GHG emission targets as in South Africa, or focus on domestic goals only, for example as in China and India (Bailey & Compston, 2012). Both of these types of targets are considered commitments, and it could lead to overall GHG mitigation. The South African initiatives around the Energy Efficiency Accord, are both a national commitment for establishing the incentive schemes and a company-specific commitment for reducing GHG emissions below a baseline (Tyler, 2010). Using these commitments as a basis, the performance of the South African mining industry should be evaluated, against this baseline, as it is one of the key sectors of the country. However, after a decade, the uncertainty of metrics and complexity of boundaries would make it difficult to determine actual progress or achievement of the commitments made in the Energy Efficiency Accord.

This is similar to the European Union that met, and exceeded, the % reduction target under the 1990 baseline (section 2.4), with external factors leading to reduced emissions and not mitigation actions. A shrinking economy is not transformational and would lead to other sustainable development goals not being met. Similarly, fast-growing cities, especially in developing countries, should focus on meeting the sustainable development goals, providing basic services and preventing slum formation, on the journey towards a low carbon and climate resilient city. The reduction targets should, therefore, include the unmet demand for basic services.

Metrics and goal setting should, however, be followed up with an analysis to enable learning and improved target setting. Energy and energy efficiency analyses, such as the South African decomposition studies, showing the patterns of energy consumption in the economy, or sectoral studies on GHG emissions from surface and abandoned coal mines provided peer-reviewed baseline data (R. Inglesi-Lotz & Pouris, 2012), (Cook & Lloyd, 2012). These types of studies supported the implementation of the South African Energy Efficiency Accord. Similar studies have not been done or published since 2013. Evaluation of the actions and policies or strengthening of decarbonisation policies based on lessons learned cannot be done without information. Especially the growing role of energy efficiency in reducing GHG emissions would require analysis of the implemented projects to date. In principle, the implementation of energy efficiency activities could be a key component of decarbonisation in South Africa. Improvements in energy efficiency provide an opportunity for economic growth, while also providing broader access to energy services. According to the International Energy Agency, improvements in energy efficiency show the greatest potential of any single strategy to abate global GHG emissions from the energy sector (Ryan et al., 2012). Metrics and improved forecasting tools are essential to realising this potential in South Africa.

Transparency in boundary setting is essential to tracking progress against targets. However, where boundaries change, such as changing city demarcation or the acquisition of new mines, the inventory should be restated instead of changing the target. This is the case for most targets except an absolute reduction by a target year. Moving emission sources out of the boundary is not a mitigation action and should, therefore, not count towards meeting such a goal.

How can an ex-post analysis assist in setting GHG emission reduction targets?

In this research, it is shown that tracking the progress of implemented GHG emission reduction initiatives against a fixed baseline target in the mining sector is complex. A decade after signing a voluntary accord to reduce GHG emissions by 15%, data is available in the public domain to carry out the tracking of GHG emissions analysis for signatories to this Accord. However, the analysis can be complex as the companies do not necessarily own all the emission sources that formed part of the company when the accord was signed, and some of the intended projects have not been implemented. The accord was dissolved in 2013 due to financial constraints on the side of Government in maintaining the incentives. Therefore, the analysis of the progress over the decade, against the 15% reduction commitment, is done for academic interest, to test to the metrics and methodology. However, of the two companies evaluated, it seems that the facilities, owned by Gold Fields in 2005, have achieved the commitment made to the Energy Efficiency Accord, based on lower actual GHG emissions than those that were forecast initially. Based on the information in the public domain and due to the large stripping ratio for Kumba's mines, Kumba did not meet the commitment. The published emission reduction activities implemented in both companies are likely to be understated, as only large-scale projects were reported on in the public domain and, therefore, the performances against the targets might have been better than currently represented.

It is likely that similar long-term commitments could be made under either a future mandatory regime, such as the proposed South African carbon budget system or another voluntary regime, such as article 6 of the Paris Agreement. Participating companies making such commitments should take care in defining the metrics of progress measurement and ensure compliance is drafted as part of mergers or divestments. Also, a new GHG baseline and target value should be calculated and linked to the revised emission sources of the new entities following such mergers or divestments. Cities should include revisions of GHG targets in the process of changing demarcation when the change in boundary could lead to a move of material GHG emission sources in or out of the boundary.

The ex-post methodology to create an actual GHG baseline, using two existing data sets, to derive the benchmark or distance from a target has been effective in evaluating the progress against targets in the mining sector. The first set of data is the actual emissions of the facility or company. The second set of data is implemented emission reduction activities and the GHG emission reductions achieved. The counterfactual baseline is the sum of the GHG emissions and the achieved emission reductions over the target period. This counterfactual baseline would be the theoretical emission trajectory for a company if the emission reduction activities were not implemented. The counterfactual baseline approach meets the criteria of:

- Past accuracy, being able to track the progress against emission targets in the respective mining companies,
- Sound representation of the current system, based on actual updated annual GHG inventories,
- Transparency, it is possible to see the underlying mitigation activities that resulted in a decrease of emissions, and
- The ability to conduct sensitivity analyses, of which the changes in the grid emission factor are the biggest contributor for energy-intensive mining companies and coal calorific values for the national inventory.

The counterfactual baseline, together with the implemented initiatives, provides a realistic picture of emission reductions achieved independently of a large number of operational, GHG accounting factors and external factors. This model can support decarbonisation and allow for planning and policies that support climate action, as well as enabling the monitoring of progress towards meeting the Paris Agreement.

7.3. Conclusions about the research problem

Implementation of the Paris Agreement has just started, and the detail is being developed. However, what matters are the mitigation actions that have, and will be implemented in the future. Combining an inventory with the implemented mitigation actions is a useful approach in dealing with data gaps and tracking the decarbonisation of a country, city or company. Making progress in decarbonisation and tracking the emissions trajectory over time will be key to meeting the objectives of the Paris agreement. Communicating progress in an climate action infograph may also foster understanding about trajectories and prove ambition despite difficult external influences.

Improved national inventories and transparent uncertainty management is essential in understanding the absolute GHG emissions and trends. Reporting on mitigation actions from both national and subnational actors is, therefore, important in maintaining the focus on global reduction of GHG emissions and improved carbon sinks. The role of these actions in constructing a decarbonisation trajectory must be clearly articulated as part of the implementation plan of the Paris Agreement.

A methodological approach is proposed where the actual annual emissions from trade statistics are quantified and presented together with the actual emission reduction estimates of implemented mitigation actions. Reporting both the total absolute emissions and total mitigation achieved allows for tracking progress against commitments, and is useful especially in countries with higher data uncertainty and delayed published GHG inventories. Uncertainty in national GHG inventories should not hinder the implementation of mitigation actions. Transparent tracking of progress and planning of appropriate mitigation policies will ease the access to financial, technological and other forms of support.

An ex-post methodology on the inventory and implemented mitigation actions will provide the input required for adjustments on forecast values. National mitigation policies and measures can be adjusted to ensure effectiveness and avoid unnecessary costs of mitigation actions. This is supported by the optimising model of mitigation and adaptation, showing that the joint implementation of mitigation and adaptation improves welfare (Bosello, Carraro, & De Cian, 2010). In this model, mitigation action should start immediately, whereas adaptation can commence later.

Increased transparency in the form of an infographic containing the inventory, forecast, target and counter factual baseline would be useful to keep the focus on the mitigation of GHG emissions.

7.4. Implications for theory

Although prior studies typically considered either the targets, mitigation actions, or the GHG trajectories, this paper's results offer extra insight. It suggests that combining these provides the improved understanding of the GHG trajectory for improved target setting., largely ignored in the existing literature. Setting greenhouse gas targets against a business as usual trajectory can only be possible over a short period. Over time the reduced greenhouse gas trajectory, that includes the mitigation initiatives, become the new business as usual trajectory. The combination of external influences, such as reduced demand, on the greenhouse gas inventory makes it difficult to separate the influence of mitigation initiatives within the current established accounting frameworks. The different accounting frameworks of the greenhouse gas inventories for different entities requires harmonisation in order be utilised as input on other platforms. Communication of the climate action trajectory against a target, is essential to inspire increased ambition.

Although current theory pays increasing attention to trade-offs between:

- Meeting the Sustainable Development Goals on poverty reduction and sustainable energy for all, in combination with the commitments made under the Paris Agreement
- Meeting the suppressed demand for basic services and decarbonising cities,
- Meeting the science based GHG reduction targets while meeting the growth needs of the investors

this is not yet reflected in either the framing of the commitments or targets or the communication of the performace trajectory. The complexity of the trade-off calculation and the increased data demand has not yet been addressed. This is a field that needs further exploration in how to reflect the trade off. An infographic enhances understanding of the impact of these dynamics on each other.

Restatement of the historical inventories is important and will occur over time due to methodological changes or corrections of either emission factors or activity data. The current theory behind all the inventory platforms, accounting frameworks does address the aspect of uncertainty. However, without clear documentation and communication, there are risks that version control may over the medium to long term become challenging. The inventories, default factors and targets in modelling contains to a very limited extent the uncertainties and awareness around the impact of these on the results are not visible. The communication of the sensitivities on the infographic could be visualised as a thicker line to avoid misleading conclusion

7.5. Implications for policy and practice

7.5.1. Private sector

After the Paris climate change meeting in 2015, there is an agreement to reduce GHG emissions globally, but there is no internationally binding policy guidance on decarbonisation. Each country can develop their own approach per sector, consistent with their respective development priorities. The proposed country trajectories should contain a sequence of sectoral changes in physical infrastructure, deployment of technologies, investment or consumption (Bataille et al., 2016). To develop these trajectories, information and metrics to reflect the actual change must be made available, even without mandatory greenhouse reporting regulations, such as in South Africa. According to the 2015 annual report of the Chamber of Mines, the mining sector in South Africa is already struggling to remain competitive and to attract investment for growth (Chamber of Mines, 2016). With mining being both energy and trade intensive, it is essential that disclosure and policies should be developed carefully to maintain the competitiveness of the country (Winkler et al., 2010).

Targets framed as a reduction against business as usual can be perceived as beneficial initially as it does not restrain growth. However, tracking performance and communicating the distance to target is challenging. Over time the deviation from business as usual, becomes the new business as usual.

Where consolidated mitigation values are visualised, and published together with the total inventory, it will give implementing agencies recognition and can be a form of self-calibration (how much could be saved from solar street lights, fuels switch or changing transport modes is less abstract than the total budget spent on mitigation or total GHG reduction) on the impact of mitigation initiatives.

7.5.2. Public sector

Climate change laws and policies do not operate only through direct incentives; they have a number of indirect effects. These include: creating integrating institutions, changing incentive structures for bureaucracies, generating new sources of data and metrics that affect bureaucratic functioning, generating political opportunities, providing signals to the private sector, providing "hooks" around which civil society can organize and mobilize, and inducing normative shifts in favour of effective mitigation action (Dubash & Hagemann, 2013). These should be harnessed to inspire increased mitigation action. Quantifying the GHG emissions impact of life style changes and supporting energy efficiency activities will support the overall reduction of GHG emissions and should be recognised and reflected as mitigation initiatives

In China, a clear policy in supply-side restructuring is already reducing emissions and will continue to do so in 2020 while growing their economy (Yang, Liu, Su & Jing, 2017).

In contrast, the South African economy did not grow as expected, in fact- economy is contracting. Although this will also lead to a reduction in GHG emissions, the possible negative impact on employment could have serious political implications. Studies on the impact of a carbon price in South Africa indicated that the emission-intensive sectors, such as metals and mining, are not as labour intensive as services. The active labour unions will, however, buffer any impact as the lack of alternative employment contributes to escalating unemployment rates (Arndt, Davies, & Thurlow 2011).

The impact of energy reduction initiatives on the energy consumption patterns and the GHG inventories are, however, not clear. New methods for GHG target setting should be explored, to support the development of effective decarbonisation policies.

A large number of developing countries rely on coal-based electricity generation. In China, India, and South Africa coal-based energy remains the primary source of GHGs. In this paper, it is found that there is a 20% over-reporting of primary energy emissions in the 2010 GHG inventory of South Africa. This error is linked to the use of a Tier 1 calculation methodology of the 2006 IPCC Guidelines. Transparency in coal types and coal calorific values used in the national inventory would, therefore, significantly reduce the uncertainty in these inventories.

Restating the GHG emissions for improved accuracy will add complications in tracking progress against the commitments made under the Paris agreement. However, the benefit would be realistic emission estimates and a focus on actual mitigation actions. Provisions in the Paris Agreement should require countries to regularly review, update and strengthen the calculation of mitigation actions.

The effectiveness of land-use strategies is difficult to measure because of the interdependence of the different components in the built environment, e.g. population growth, behavioural and attitudinal

forces, economic growth and development patterns, etc. A reasonable assessment of the GHG impacts of land use strategies can be done by conducting revealed preference surveys. A revealed preference survey is a method of analysing choices made by individuals, mostly used for comparing the influence of policies on consumer behaviour. The survey in question must assess the travel choices made before and after implementation of the land use strategies. Revealed preference surveys require adequate time for survey planning and stakeholder engagement.

To accurately assess the estimates of the effectiveness indicators, from one project to the next, the input data and information for each mitigation response measure needs to be comparable. Estimates of cost-effectiveness and job-creation effectiveness of a mitigation response measure, require data on the number of jobs and the costs involved in implementing that measure. These sets of data are often not reported consistently by the implementation agencies and cover information associated with a number of transport projects, making it difficult to isolate the information required for a specific project. For these indicators to be estimated accurately in the future, it is recommended that implementation and management agencies provide data that is consistent with, and comparable to, not only to their own historical datasets - but also to the information and data provided by other agencies.

In an evaluation of policy implementation in Western Europe, the need for not only improved accounting of GHG emissions and forecasts, but also of mitigation options, has been highlighted as essential to support improved target setting and national mitigation strategies. Even though cyclical monitoring and reporting is in place and supported by national strategies, it has played a limited role in facilitating research (Casado-Asensio & Steurer, 2015). For sectors, cities and countries to receive the support, it is essential to communicate the mitigation options available and publish research, to enable informed policy making.

Transparency is thus key in the journey to the low carbon economy. An ex-post methodology on the inventory and implemented mitigation actions will provide the input required for adjustments on forecast values. National mitigation policies and measures can be adjusted to ensure effectiveness and avoid unnecessary costs of mitigation actions.

7.6. Limitations

Four different limitations became apparent during the development of the ex-post analysis:

- Mixing project-based mitigation with national top-down mitigation estimates increases the risk of double counting of GHG reductions. Sector-based evaluations of reduced energy demand should not be added to the individual projects implemented, as double counting would over estimate the reduction achieved.
- Methodological differences for estimating mitigation emissions, especially for greenfields project can make extrapolations difficult. The theoretical GHG emissions of baseline projects never built can be overestimated to meet the GHG target. This is the case for electricity utilities that could use inefficient technology as a baseline to claim savings for efficient coal based electricity generation technology.
- Double counting of the same project under different mitigation programmes, such as energy efficiency and carbon credits.
- Restatement of the historical inventories due to methodological changes or corrections of either emission factors or activity data. Without an affordable system maintaining documentation data and public communication, there is a risk that version control can become challenging.
- Methodological diversity in public carbon disclosure, across all sectors, can be limiting for general climate change related decision-making and the development of policies or strategies.

7.7. Implications for further research

Combining the emission inventory ex-post with the implemented mitigation actions is a useful approach in dealing with data gaps and tracking decarbonisation. However, improved national inventories and transparent uncertainty management is important in understanding the absolute GHG emissions and trends. Reporting on mitigation actions from both national and subnational actors is important to maintain the focus on global reduction of GHG emissions and to improve carbon sinks. The role of these actions in constructing a decarbonisation trajectory must be clearly articulated as part of the implementation plan of the Paris Agreement.

Accounting for transnational climate change action of value chains across various countries is well researched (Hale, 2016),(Newell et al., 2015),(Chan et al., 2015),(Hoppe et al., 2013), but it is not yet clear how these link with national reduction commitments. The lack of clarity is because accounting is done on different platforms with different sectoral classification and inconsistent methodologies. Climate action in the private sector, cities and subnational initiatives are published on an ad-hoc basis, with little-standardised methodologies. However, in principle, standardisation could be possible.

This study provided an infographic with a counterfactual baseline on what has been implemented against the short to medium term targets. This could be expanded to include the far future and the implication of mitigation policies or plans. Such an ex-ante projection would compliment the ex-post analysis and would be in line with the framework for post 2020 mitigation effort proposed for comparing countries (Aldy et al., 2017)

This could also be a possible application for blockchain technology as an affordable avenue to track progress while supporting version control and maintaining trust in the outcome.. The activity data in most cases can be continually tracked, and the emission factors can be verified. Therefore the inventory can be continually updated. The same for the mitigation actions. Therefore the distance to target at a given time could be available with little cost and without concerns about version control, previous datasets or calculations, or staff changing functions. The components of the climate action infographic lend themselves to being fixed in blockchain, and continuously updated. Carbon credits, as a verified mitigation action, is already utilising blockchain technology and the UNFCCC is evaluating it under the next phase.

8. References

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9. Addendum: Data used for analyses

9.1. National GHG inventory, target and mitigation calculations and data

Annual national fuel consumption in million litres (SAPIA, 2015) . Note 2016 and 2017 data was received directly from SAPIA

Table 9-1 Annual fuel consumption in million litres

	Petrol	Diesel	Paraffin	Jet fuel	Fuel oil	LPG
2006	11279	8708	738	2260	476	605
2007	11558	9755	696	2402	465	636
2008	11069	9762	532	2376	555	613
2009	11321	9437	551	2349	724	554
2010	11455	10170	545	2308	468	612
2011	11963	11225	581	2434	477	717
2012	11714	11262	470	2367	568	656
2013	11153	11890	530	2233	523	485
2014	11344	13169	558	2197	487	398
2015	12072	14178	573	2441	591	588
2016	10160	10846	558	2121	562	557
2017	11174	12147	648	2713	523	551

Default calorific values and densities from the Technical guidelines for monitoring, reporting and verification of greenhouse gas emissions for industry (sourced from the Department of Environmental Affairs website). These values have to be used for mandatory GHG reporting (Department of Environmental Affairs, 2017)

Table 9-2 Calorific values and densities

	Petrol	Diesel	Paraffin	Jet fuel	Fuel oil	LPG
CV	MJ/l	MJ/l	MJ/l	MJ/l	MJ/kg	MJ/kg
	34,2	38,1	37,5	37,5	42	46,1
Density					kg/l	kg/l
					0,99	0,555
Emission factors	kgCO2/TJ	kgCO2/TJ	kgCO2/TJ	kgCO2/TJ	kgCO2/TJ	kgCO2/TJ
	69300	74100	71900	70000	73300	63100

GHG emissions in the SA GHG inventory (Department of Environmental Affairs Republic of South Africa, 2014)

Table 9-3 GHG emissions in the SA GHG inventory in Mton CO2 eq

Year	Updated GHG inventory 2000-2012 (excl sequestration)	Energy % in inventory	Electricity related emissions	Non-electricity energy emissions	Process emissions	Agriculture and land use emissions (excl sequestration)	Waste emissions
2000	452	340	186	154	45	55	12
2001	452	339	181	158	45	54	13
2002	467	350	187	163	47	55	14
2003	490	374	204	170	48	53	15
2004	508	391	212	179	48	53	16
2005	503	384	210	174	51	53	17
2006	513	391	212	178	52	53	17
2007	540	419	234	185	50	53	18
2008	528	410	223	187	46	53	19
2009	533	419	230	189	43	52	20
2010	552	432	237	195	46	54	20
2011	535	413	235	177	48	54	21
2012	545	424	246	178	47	52	22
2013	522	401	228	173	48	52	22
2014	529	408	233	174	48	52	22
2015	525	404	223	180	48	52	22
2016	514	393	216	177	48	52	22
2017	515	394	211	183	48	52	22

South Africa’s National Determined Contribution (NDC)

South Africa’s mitigation component of its INDC moves from a “deviation from business-as-usual” form of commitment and takes the form of a peak, plateau and decline GHG emissions trajectory range. South Africa’s emissions by 2025 and 2030 will be in a range between 398 and 614 Mt CO2–eq, as defined in national policy. PPD trajectory range: South Africa’s NCCRP “details the ‘peak, plateau and decline trajectory’ used as the initial benchmark against which the efficacy of mitigation actions will be measured”. This is the PPD trajectory range in the INDC. Values for key years are specified in the NCCRP (Department of Environmental Affairs Republic of South Africa, 2015)

Table 9-4 Boundaries of the South Africa’s National Determined Contribution (NDC) in MtonCO2 eq

Year	NDC target upper limit	NDC target lower limit
2010	547	398
2011	550	398
2012	553	398
2013	556	398
2014	559	398
2015	562	398
2016	565	398
2017	568	398
2018	571	398
2019	574	398
2020	583	398
2021	589	398
2022	595	398
2023	601	398
2024	607	398

2025	614	398
2026	614	398
2027	614	398
2028	614	398
2029	614	398
2030	614	398
2031	614	398
2032	614	398
2033	614	398
2034	614	398
2035	614	398
2036	602	386
2037	589	373
2038	577	361
2039	564	348
2040	562	336
2041	540	324
2042	527	311
2043	515	299
2044	502	286
2045	490	274
2046	478	262
2047	465	249
2048	453	237
2049	440	224
2050	428	212

National mitigation actions from South Africa's second climate change report, Sasol CDP report, Eskom annual report and CDM project list for South Africa

Table 9-5 National mitigation action

		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Energy efficiency															
	RE IPP							0	0	0	1,65	3,3	5,6	8,6	11,1
	Eskom IDM	0,9	1,62	4,32	10,16	19,33	23,06	29,94	35,81	38,6	50,6	62,6	62,6	62,6	62,6
	Eskom EE										28,9	48,3	58,7	60,4	66,4
	12L							0		0	2,85	5,7	5,7	5,8	5,934
	Sasol EE							1,68	1,88	2,692	0	0,18774	0,25	0,25	0,286
	Municipalities									0,2	0,35	0,5	0,5	0,5	0,5
	DEA green building									0	0,000025	0,00005	0,00005	0,00005	0,00005
Transport	BRT JHB									0,03	0,06	0,09	0,12	0,15	0,18
	BRT CPT									0,05	0,1	0,15	0,2	0,25	0,3
	Taxi recap									0,7	0,95	1,2	1,2	1,2	1,2
	CNG verhicles									0	0,0015	0,003	0,003	0,003	0,003
	Transnet MPP									0	0	0	0	0	0
	Transnet Road to rail									0,4	1,05	1,7	1,7	1,7	1,7
	Biofuels									0,0002	0,00025	0,0003	0,0003	0,0003	0,0003
AFOLU	working for programmes									0	0,02	0,04	0,04	0,04	0,04
Waste	Biogas									0,4	0,45	0,5	0,5	0,5	0,5
	composting									0,5	0,7	0,9	0,9	0,9	0,9
	landfill gas									2,1	2,75	3,4	3,4	3,4	3,4
	MRF									0,02	0,03	0,04	0,04	0,04	0,04
Industry	Sasol Fuel switch (7,35MtCO2/year	7,35	14,7	22,05	29,4	36,75	44,1	51,45	58,8	66,15	73,5	80,85	88,2	95,55	102,9
	CDM					0,50	1,12	1,78	3,40	4,40	10	15,6	15,6	15,6	15,6
	Sasol gas turbines									0,32	0,64	0,96	1,28	1,6	1,92
	Namakwa Sands energy										0				
	CNG fuel switch							0		0	0,004	0,008	0,008	0,008	0,008
	IPAP							0		0,4	0,85	1,3	1,3	1,3	1,3
	Total	8,3	16,3	26,4	39,6	56,6	68,3	84,8	99,9	117,0	175,5	227,3	247,8	260,4	276,8

9.2. Mining company GHG inventory, mitigation and target data and calculations

Underground Gold Mining (Gold Fields and Sibanye)

All South African mines included in the reporting boundary. These are Driefontein, Kloof, Beatrix and South Deep

Table 9-6 Gold Fields greenhouse gas data for CDP

Savings (tCO2e)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Verified GHG emissions inventory Gold Fields	4565899	4705511	4573384	4993427	5138083	5853421	794844	537854	559298	498055	496199
Verified GHG emission inventory Sibanye							5098338	5485174	5239123	5174658	5271782
Combined GHG emissions inventory	**4565899**	**4705511**	**4573384**	**4993427**	**5138083**	**5853421**	**5893182**	**6023028**	**5798421**	**5672713**	**5767981**
Compressed Air							18751	78157	133934	175179	175180
Energy efficiency other			455548	455548	455548	455548	455548	457271	466420	478402	480870
Energy efficient lighting			312	312	312			2419	3452	3452	3452
Process optimisation							56562	75527	144896	160939	160939
Pumping								3903	3903	3903	3903
Renewable energy				67000	67000	67000	67099	92075	92075	92075	92075
Ventilation					13140	36295	82750	122754	225305	276470	276470
Water Heating							41	2684	2684	2684	2684
Methane Capture							253329	253329	253329	253329	253329
Counter factual baseline	**4565899**	**4705511**	**5029244**	**5516286**	**5674083**	**6412264**	**6827262**	**7111148**	**7124419**	**7119146**	**7216883**

Baseline Scenario based on two Intensity metrics

Table 9-7 Gold mining baseline scenario for two intensity metrics

Baseline Scenario Using Production Intensity	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Ex-ante baseline scenario	437117	447967	470366	493884	518578	660111	693117	727773	764162
Ex-ante policy scenario	437117	443488	460958	479067	497835	627106	651530	676829	703029
Ex-poste baseline scenario	437117	465762	493101	513524	569428	695878	838813	913720	966554
Ex-poste policy scenario	437117	465762	493101	513524	569428	695878	838422	903767	942413
Baseline Scenario Using Tonnes Mined Intensity	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Ex-ante baseline scenario	437117	458973	481921	506017	531318	637307	669173	702631	737763
Ex-ante policy scenario	437117	454383	472283	490837	510066	605442	629022	653447	678742
Ex-poste baseline scenario	437117	465762	493101	513524	569428	695878	838813	913720	966554
Ex-poste policy scenario	437117	465762	493101	513524	569428	695878	838422	903767	942413

Table 9-8 Gold Fields target on both intensity metrics

	Target for gold produced metric	Target for tonnes milled metric
2005	4952930	4952930
2006	5024995	4903029
2007	5096927	4852506
2008	5168652	4822292
2009	5240093	4791271
2010	5311168	4759426
2011	5381792	4726737
2012	5451874	4693183
2013	5521317	4658745
2014	5590020	4623402
2015	5657875	4587131

Opencast iron ore mine Kumba: Included in the reporting boundary is Sishen, Thabazimbi and Kolomela

Production Forecast

Table 9-9 Kumba production forecast

Operation		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Sishen forecast production			29721362	29721362	29164087	29164087	29164087	29164087	29164087	29164087	29164087	29164087	29164087
Sishen Expansion Project			0	0	1857585	8823529	11331269	12631579	12631579	12631579	12631579	12631579	12631579
Sishen South (Kolomela)			0	0	0	0	0	928793	7708978	9195046	9195046	9195046	9195046
Thabazimbi			3529412	3529412	3529412	3529412	3529412	2043344	0	0	0	0	0
Phoenix			0	0	0	0	0	1857585	2879257	2879257	2879257	2879257	2879257
Sishen Expansion Project 2 Phase 1			0	0	0	0	0	6687307	12538700	12910217	12910217	12910217	12910217
Pellets			0	0	0	0	0	0	2600619	2600619	2600619	2600619	2600619
Total production forecast			**33250774**	**33250774**	**34551084**	**41517028**	**44024768**	**53312693**	**67523220**	**69380805**	**69380805**	**69380805**	**69380805**

Mitigation initiatives

Table 9-10 Kumba mitigation initiatives

Cumulative Savings	2009	2010	2011	2012	2013	2014	2015
HVAC	-	-	149	149	149	149	149
Lighting	-	-	292	292	489	1 593	1 593
Liquid fuels	-	-	254	274	10 062	19 333	27 540
Motors	-	-	266	266	266	724	724
Power Supply	-	-	169	169	169	169	169
Process Optimisation	-	326	9 771	12 121	15 489	16 443	16 443
Pumping	-	-	1 175	3 358	8 127	11 454	11 454
Water Heating	-	79	3 506	3 506	5 610	5 892	5 892
Buildings	-	-	-	-	26	26	26
Compressed Air	-	-	-	174	174	174	174
Conveyors	-	-	-	-	405	405	405
Meter and Monitor	-	-	-	-	-	27	27

Table 9-11 Verified production and performance values

Sishen Mine	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
	87 431 667	90 315 773	90 329 392	103 909 604	108 805 874	128 314 099	153 200 000	165 000 000	171 600 000	208 800 000	252 200 000	261 400 000
Total tonnes mined Mt	59 822 534	61 858 193	61 637 415	74 360 433	80 256 333	99 363 032	111 900 000	126 101 000	137 903 000	177 860 000	216 700 000	230 000 000
Waste mined	27 609 133	28 457 580	28 691 977	29 549 171	28 549 542	28 951 067	41 300 000	38 899 000	33 697 000	30 940 000	35 500 000	31 400 000
Final Product	3,17	3,17	3,15	3,52	3,81	4,43	3,71	4,24	5,09	6,75	7,10	8,32
Stripping Ratio												
Thabazimbi	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
	27 210 485	27 820 000	21 730 000	20 000 000	12 100 000	19 500 000	35 500 000	45 900 000	32 200 000	27 200 000	32 800 000	10 200 000
Total tonnes mined Mt	24 570 485	25 276 000	19 030 000	17 186 079	9 129 805	16 583 511	33 500 000	44 997 000	31 376 000	26 600 000	31 700 000	10 200 000
Waste mined	2 640 000	2 544 000	2 700 000	2 813 921	2 970 195	2 916 489	2 000 000	903 000	824 000	600 000	1 100 000	-
Final Product	10,31	10,94	8,05	7,11	4,07	6,69	17,75	50,83	39,08	45,33	29,82	-
Stripping Ratio												
Kolomela	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
	0	0	0	0	0	0	18600000	34600000	43500000	67500000	75400000	60600000
Total tonnes mined Mt	-	-	-	-	-	-	18 600 000	33 134 000	34 955 000	56 700 000	63 800 000	48 500 000
Waste mined	0	0	0	0	0	0	0	1466000	8545000	10800000	11600000	12100000
Final Product	-	-	-	-	-	-	-	23,60	5,09	6,25	6,50	5,01
Stripping Ratio												
	3,79	3,81	3,57	3,83	3,84	4,64	4,79	5,95	5,74	7,17	7,48	7,64
Overall Stripping Ratio	30 249 133	31 001 580	31 391 977	32 363 092	31 519 737	31 867 556	43 300 000	41 268 000	43 066 000	42 340 000	48 200 000	43 500 000

9.3. City GHG data and calculations

The data for the city GHG calculations are based on four main sources, all publicly available. These are shaded in different colours. Data in uncoloured cells are interpolations, extrapolations or calculations.

Data from C40
Data from StatsSA CS2016
Data from StatsSa labour force participation survey
StatSA/statistics by place

The four metropolitan cities have submitted GHG inventories to C40 cities according to the Global Protocol for Community-scale (GPC) GHG Emission Inventories methodology. The Greenhouse Gas Emissions Interactive Dashboard (GHG Dashboard) and associated data is made available for public use as part of a C40-wide initiative to improve the accessibility and transparency of public data, reported by C40 member cities. The GHG Dashboard allows for easy access, analysis and visualisation of the available historical greenhouse gas emissions data reported by C40 cities via Global Protocol for Community-scale (GPC) GHG Emission Inventories and accessed through C40's partner, CDP Cities. The reference is GHG Interactive Dashboard Data. 2017. London, UK: C40 Ci ties Climate Leadership Group and can be accessed via http://www.c40.org/other/gpc-dashboard

The four South African cities report on BASIC level. At this level it includes all scope 1 sources except from energy generation, imported waste, IPPU, and AFOLU, as well as all scope 2 sources. The values used in this study includes the citizen population reported for the year, the Cape Town has already updated their GHG inventory and both years, 2012 and 2015 were used in the calculated. Tshwane, Ekurhuleni and Johannesburg has submitted once on 2013, 2014 and 2014 respectively.

Table 9-12 The GPC taxonomy and relevant categories included

GPC ref	Description	Scope	Sector	Sub-Sector
I.1.1	Emissions from fuel combustion within the city boundary	1	Stationary	Residential Buildings
I.1.2	Emissions from grid-supplied energy consumed within the city boundary	2	Stationary	Residential Buildings
I.2.1	Emissions from fuel combustion within the city boundary	1	Stationary	Commercial and institutional buildings and facilities
I.2.2	Emissions from grid-supplied energy consumed within the city boundary	2	Stationary	Commercial and institutional buildings and facilities
I.3.1	Emissions from fuel combustion within the city boundary	1	Stationary	Manufacturing industries and construction
I.3.2	Emissions from grid-supplied energy consumed within the city boundary	2	Stationary	Manufacturing industries and construction
I.4.1	Emissions from energy used in power plant auxiliary operations within the city	1	Stationary	Energy industries
I.4.2	Emissions from grid-supplied energy consumed in power plant auxiliary operations within the city	2	Stationary	Energy industries
I.5.1	Emissions from fuel combustion within the city boundary	1	Stationary	Agriculture, forestry, and fishing activities
I.5.2	Emissions from grid-supplied energy consumed within the city boundary	2	Stationary	Agriculture, forestry, and fishing activities
I.6.2	Emissions from grid-supplied energy consumed within the city boundary	2	Stationary	Non-specified sources
II.1.1	Emissions from fuel combustion on-road transportation occurring in the city	1	Transport	On-road
II.1.2	Emissions from grid-supplied energy consumed in the city for on-road transportation	2	Transport	On-road
II.2.1	Emissions from fuel combustion for railway transportation occurring in the city	1	Transport	Railways
II.2.2	Emissions from grid-supplied energy consumed in the city for railways	2	Transport	Railways
II.3.1	Emissions from fuel combustion for waterborne navigation occurring in the city	1	Transport	Waterborne navigation
II.3.2	Emissions from grid-supplied energy consumed in the city for waterborne navigation	2	Transport	Waterborne navigation
III.1.1	Emissions from solid waste generated in the city and disposed in landfills or open dumps within the city	1	Waste	Solid waste generated in the city
III.4.1	Emissions from wastewater generated and treated within the city	1	Waste	Wastewater generated in the city

National values used for all four cities are minimum supply of drinking water, sanitation and basic electricity provision.

The right of access to sufficient water is protected in s. 27(1)(b) of the Constitution. According to national regulations, everyone has the right to a minimum basic water supply (Water Services Act, Regulations Relating to Compulsory National Standards and Measures to Conserve Water (GN 22355 of 8 June 2001). According to regulation 3(b), the minimum supply for basic water is a minimum amount of 25 litres per person per day or 6 000 litres (6 kilolitres) per household per month (a household is defined as everyone living on one stand). It was assumed the current system, and associated GHG emissions will either incorporate the provision of water to these citizens or be extended to meet this need.

There is no right to electricity in the Constitution, but there is a right to basic municipal services in s. 73 of the Municipal Systems Act. National laws state that local municipalities should have a policy to provide free basic water and free basic electricity to people who cannot afford to pay for these services (s. 73 of the Municipal Systems Act). The national standard for free basic water is 50 kilowatt hours (kWh) of free basic electricity per household per month. It was assumed the current system, and associated GHG emissions will either incorporate the provision of electricity to these citizens or be extended to meet this need.

There is no right to sanitation in the Constitution, but it is part of the right to basic municipal services in s. 73 of the Municipal Systems Act, and it is protected by Regulation 2 of the Water Services Act, Regulations Relating to Compulsory National Standards and Measures to Conserve Water (GN 22355 of 8 June 2001), which states that the minimum standard for basic sanitation services is "a toilet that is safe, reliable, environmentally sound, easy to keep clean, provides privacy and protection against the weather, well ventilated, keeps smells to a minimum and prevents the entry and exit of flies and other disease-carrying pests". It was assumed the current system, and associated GHG emissions will either incorporate the provision of sanitation to these citizens or be extended to meet this need.

Addressing un employment is an overarching priority of the government. In the National Development Plan (page 38) the goal is stated " In 2030, the economy should be close to full employment, equip people with the skills they need, ensure that ownership of production is more diverse and able to grow rapidly, and provide the resources to pay for investment in human and physical capital." A critical action is therefore(page 37) " A strategy to address poverty and its impacts by broadening access to employment….. improving public transport.." In 2016 South Africa committed to aligning itself with the 2030 Agenda for Sustainable Development Goals (SDGs) (www.sanews.gov.za ,Friday, April 22, 2016). Sustainable Development Goal 8 is to "promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all". Statistics South Africa performce and publishes a quarterly survey to establish The South African working-age population. The Quarterly Labour Force Survey (QLFS) is a household-based sample survey conducted by Statistics South Africa (Stats SA). It collects data on the labour market activities of individuals aged 15 years and older who live in South Africa. However, this report only covers labour market activities of persons aged 15–64 years (the South African working-age population) (http://www.statssa.gov.za/publications/P0211). It was assumed that the current transport system, and associated emissions, will expand to absorb the additional travel requirements of the currently unemployed to participate in the labour market within the borders of the metropolitan city

In the community survey 2016, households were asked about the installation of a solar water heater instead of electric geyser

Table 9-13 Solar water heater installations per city

	City of Cape Town	eThekwini	City of Johannesburg	City of Tshwane
Yes	408459	380426	592734	332562
No	703670	564533	888493	602801
Not applicable (for those households who indicated that they have no access to electricity)	22992	40914	154230	78643
Unspecified	129828	139894	217913	122871
% households with SWH	0,32888337	0,350670552	0,348843533	0,314261307
%households without electricity	0,01851272	0,037713865	0,090769448	0,074315322

9.3.1. Cape Town

Table 9-14 Cape Town population statistics

Year	Population	Household	Household size
2010			
2011	3740031	1068515	3,5
2012	3837414	1096404	
2013	3895756	1113073	
2014	3954099	1129742	
2015	4012441	1146412	
2016	4005016	1264949	3,2
2017	4033424	1273921	
2018	4061831	1282894	
2019	4090239	1291866	
2020	4118646	1300838	
2021	4147054	1309810	
2022	4175461	1318783	
2023	4232276	1336727	

Table 9-15 Cape Town poverty statistics

	No access to safe drinking water	No toilet facilities	No refuse removal	No access to electricity for lighting
% Households in 2016	6,3	0,84	0,66	2,4
Number of households	79 692	10 629	8 335	30 359

Table 9-16 Cape Town Unemployed people of workable age

Number of labour not involved in the labour market Quarter 4 of 2016	502000
% of 2016 population	12,53%

In 2016 South Africa committed to meeting the Sustainable Development Goals. For Cape Town it would mean providing the basic levels of service for providing at least :

- 50 litres of clean drinking water per person per day, and
- basic electricity of 0,6 kWh per household per year,
- Some form of refuse removal for each household that currently have no access to refuse removal
- Basic sanitary provision for each household that currently has no access to toilet facilities
- Employment for those that are currently unemployed and the associated transport to and from work

It was assumed that the current systems, and the associated GHG emissions, will expand to accommodate the additional requirement.

Table 9-17 Cape Town meeting the basic needs

	Acces to basic level of clean water	**Access to toilet facilities**	**Removal of refuse**	**Employees travelling to work**	**Access to basic level of energy services**	**Total**
tCO2 eq	17662	1 165	15 610	800 290	17851	852578
contribution	2%	0,1%	2%	94%	2%	

Table 9-18 Cape Town GHG inventory

Year	Energy	Transport	Waste	Suppressed demand of basic services and SDG commitments	**forecast inventory**	**Inventory**
2010						
2011	13299133	5697112	2362380			21358625
2012	13645416	5845454	2423892			21914762
2013	13476194	5763809	2447799			21687801
2014	13306971	5682164	2471706			21460841
2015	13137749	5600519	2495612			21233880
2016	13113438	5590155	2490994	852 578	21194587	22047165
2017	13206451	5629806	2508663	852 578	21344920	22197497
2018	13299465	5669457	2526331	852 578	21495253	22347830
2019	13392478	5709107	2544000	852 578	21645585	22498163
2020	13485491	5748758	2561668	852 578	21795918	22648496
2021	13578505	5788409	2579337	852 578	21946251	22798829
2022	13671518	5828060	2597006	852 578	22096584	22949161
2023	13857545	5907362	2632343	852 578	22397249	23249827

Mitigation actions in Cape Town

Over the years a variety of GHG mitigation actions have been undertaken. Detail in terms of energy saving or GHG saving is not always made public. Below is a summary of the mitigation actions that were identified and quantified as national mitigation actions. Allocation, where needed, was based on the percentage contribution to the national GDP.

Table 9-19 Cape Town mitigation actions

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Bus							2470	2340	3060	3560	3560	3560	3560
MRF			1568	1781	2198	2566	8180	7758	7427	7201	7201	7201	7201
Composting			53427	88802	112968	12000	172682	291838	309564	416624	416624	416624	416624
Taxi recapitalisation			2124	13689	22893	34457	40594	48382	54754	62307	62307	62307	62307
Solar geysers											324184	413099	529671
Glass and PET recycling	8259	23448	28812	34203	42461	53074	60523	67330	74561	72766	78277	81472	92159

9.3.2. Johannesburg

Greenhouse gas (GHGs) of a city are linked to the number of GHG emitting industries as well as the number of citizens. The non-industrial greenhouse gas emissions and mitigation actions are either linked to the number of households (for example solar water heating) or number of citizens (for example sanitation).

Table 9-20 Johannesburg population statistics

Year	Population	Household	Household size
2010			
2011	4434827	1434785	3,1
2012	4544994		
2013	4655162		
2014	4765329		
2015	4857363	1566891	
2016	4949397	1853371	2,7
2017	5045518	1868710	
2018	5141638	1904310	
2019	5237759	1939911	
2020	5333879	1975511	
2021	5430000	2011111	

Table 9-21 Johannesburg unemployed citizens of workable age

Number of labour not involved in the labourmarket Quarter 4 of 2016	862000
% of 2016 population	17%

Table 9-22 Johannesburg poverty statistics

	No access to safe drinking water	No toilet facilities	No refuse removal	No access to electricity for lighting
%2016	5,9	0,3	2,4	8,748028
Number of households	109349	5560	44481	162133

Table 9-23 Johannesburg GHG inventory

Year	Energy	Transport	Waste	Suppressed demand of basic services and SDG commitments	forecast inventory	Inventory
2010						
2011	14679031	6705566	1617875			23002472
2012	15043678	6872142	1658065			23573885
2013	15408326	7038717	1698256			24145299
2014	15772974	7205293	1738446			24716713
2015	16077601	7344451	1772021			25194073
2016	16382229	7483608	1805596			25671433
2017	16700383	7628945	1840662	1 733 915	26 169 989	27903905
2018	17018536	7774282	1875728	1 733 915	26 668 546	28402461
2019	17336690	7919618	1910794	1 733 915	27 167 102	28901017
2020	17654844	8064955	1945860	1 733 915	27 665 659	29399574
2021	17972998	8210292	1980925	1 733 915	28 164 215	29898130

Table 9-24 Johannesburg meeting basic needs

	Acces to basic level of clean water	Access to toilet facilities	Removal of refuse	Employees travelling to work	Access to basic level of energy services	Total
tCO_2 eq	24235	342	42084	1571919	95334	1 733 915
% contribution	1%	0%	2%	91%	5%	

Table 9-25 Johannesburg mitigation actions

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Rapid Bus Transport			-	-	-	12 550	7 590	5 960	4 050	2 140	2 140	2 140	2 140
Biogas								463	1 853	1 862	9	9	9
Landfill gas projects								97 114	77 220	55 029	55 029	55 029	55 029
Solar water heaters											362 532	436 465	440 423
Taxi recapitalisation			3 099	19 973	33 403	50 277	59 231	70 595	79 893	90 912	90 912	90 912	90 912
Glass and PET recycling	12 051	34 214	42 040	49 905	61 955	77 440	88 310	98 243	108 792	106 174	114 215	118 877	134 471
Gautrain and feeder bus						2240	6670	6795	3680	1960	1960	1960	1960

9.3.3. eThekwini (Durban)

Table 9-26 eThekwini population statistics

Year	Population	Household	Household size
2011	3476686	963011	3,6
2012	3459524		
2013	3442361		
2014	3528984		
2015	3615608	1095639	
2016	3702231	1125767	3,3
2017	3739993	1133331	
2018	3777755	1144774	
2019	3815516	1156217	
2020	3853278	1167660	

Table 9-27 eThekwini unemployed citizens of workable age

Number of labour not involved in the labour market Quarter 4 of 2016	450000
% of 2016 population	12.2%

Table 9-28 eThekwini poverty statistics

	No access to safe drinking water	No toilet facilities	No refuse removal	No access to electricity for lighting
2016	9	1	2	4
Household numbers	101 319	9 510	19 549	40 941

Table 9-29 eThekwini inventory

Year	Energy	Transport	Waste	Suppressed demand of basic services and SDG commitments	forecast inventory	Total
2011	16072356	6485222	348477			22906055
2012	15993015	6453208	346757			22792981
2013	15913675	6421194	345037			22679906
2014	16314126	6582776	353719			23250621
2015	16714576	6744359	362402			23821337
2016	17115027	6905941	371084			24392053
2017	17289595	6976380	374869	1 006 867	24640 845	25647712
2018	17464164	7046819	378654	1 006 867	24889 637	25896504
2019	17638733	7117258	382439	1 006 867	25138 430	26145297
2020	17813301	7187696	386224	1 006 867	25387 222	26394089

Table 9-30 eThekwini meeting the basic needs

	Acces to basic level of clean water	Access to toilet facilities	Removal of refuse	Employees travelling to work	Access to basic level of energy services	Total
tCO2 eq	22455	428	5692	954218	24073	1 006 867
contribution	2%	0%	1%	95%	2%	

Table 9-31 eThekwini mitigation actions

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Landfill gas projects		1636	17972	161193	221615	276787	275440	269497	268738	269365	269365	269365	269365
Taxi recapitalisation		-	1954	12 593	21060	31699	37344	44509	50371	57318	57318	57318	57318
glass and PET recycling	7598	21571	26505	31 464	39062	48825	55678	61940	68591	66940	72011	74949	84781
Solar water heaters											330075	339504	341871

9.3.4. Tshwane (Pretoria)

Table 9-32 Tshwane population statistics

Year	Population	Household	Household size
2011	2 921 488	911 498	3
2012	2 972 785		
2013	3 024 083		
2014	3 075 380		
2015	3 175 266	1 094 919	
2016	3 275 152	1 136 877	3
2017	3 329 921	1 148 249	
2018	3 384 690	1 167 135	
2019	3 439 460	1 186 021	
2020	3 494 229	1 204 906	
2021	3 548 998	1 223 792	

Table 9-33 Tshwane unemployed citizens of workable age

Number of labour not involved in the labour market Quarter 4 of 2016	522000
% of 2016 population	15,9%

Table 9-34 Tshwane poverty statistics

	No access to safe drinking water	No toilet facilities	No refuse removal	No access to electricity for lighting
2 016	10	1	3	4
Household numbers	109 140	6 821	29 559	43 242

Table 9-35 Tshwane meeting basic needs

	Access to basic level of clean water	Access to toilet facilities	Removal of refuse	Employees travelling to work	Access to basic level of energy services	Total
tCO2 eq	24189	848	45985	916321	25426	1 012 769
contribution	2%	0%	5%	90%	3%	

Table 9-36 Tshwane GHG inventory

Year	Energy	Transport	Waste	Suppressed demand of basic services and SDG commitments	forecast inventory	Inventory
2 010						
2 011	11 708 924	4 324 462	1 651 454			17 684 840
2 012	11 914 517	4 400 394	1 680 451			17 995 362
2 013	12 120 110	4 476 325	1 709 449			18 305 883
2 014	12 325 702	4 552 257	1 738 446			18 616 405
2 015	12 726 032	4 700 111	1 794 909			19 221 052
2 016	13 126 361	4 847 964	1 851 373			19 825 698
2 017	13 345 869	4 929 035	1 882 333	1 012 769	20 157 236	21 170 006
2 018	13 565 376	5 010 106	1 913 292	1 012 769	20 488 774	21 501 544
2 019	13 784 883	5 091 177	1 944 252	1 012 769	20 820 313	21 833 082
2 020	14 004 391	5 172 248	1 975 212	1 012 769	21 151 851	22 164 620
2 021	14 223 898	5 253 318	2 006 172	1 012 769	21 483 389	22 496 158

Table 9-37 Tshwane mitigation actions

Tshwane	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Biogas (SAB Rosslyn)	15260	15260	11205	9002	7596	6167	6167	6167	6167	6167	6167	6167	6167
Gautrain and feeder bus						18445	54923	5596	3031	1614	1614	1614	1614
Glass and PET recycling	7087	20120	24722	29348	36434	45540	51933	57774	63978	62438	67167	69908	79078
Taxi recapitalisation			1823	11746	19644	29567	34832	41515	46982	53463	53463	53463	53463
Solar water heaters											252346	262413	265142